TREATISE

CONTAINING

The PRACTICAL PART

OF

FORTIFICATION.

In FOUR PARTS.

Arches, and Timbers, with feveral Tables of their Dimensions.

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- II. The Knowledge of the Materials, their Properties, Qualities, and the Manner of using them.
- I. The Theory of Walls, | III. The Manner of tracing a Fortress on the Ground, the making an Estimate, and executing the Works.
 - IV. The Method of building Aquatics, as Stonebridges, Harbours, Quays, Wharfs, Sluices, and Aqueducts.

Illustrated with Twenty eight COPPER PLATES.

For the UsE of

The ROYAL ACADEMY of ARTILLERY at Woolwich.

By JOHN MULLER, Professor of ARTILLERY and FORTIFICATION.

The SECOND EDITION, with Improvements.

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HIS ROYAL HIGHNESS

GEORGE,

PRINCE of WALES.

SIR,

Itantly given by your Royal Progenitors to those who have endeavoured to make any Improvements in the useful arts and sciences, makes me flatter myself that Your Royal Highness, who give such early hopes of inheriting all their virtues, will be graciously pleased to honour the following treatise with Your Patronage.

My aim in publishing it, is to shew how fortresses may be built in the best and cheapest manner. I may venture to say, that a work of this kind has been hitherto wanting in the English language: and I may add, that the subject is most certainly of importance; experience having too often shewn the satal effects which the neglect of the art of Fortification may pro-

of Knowledge.

Your Royal Grandfather, ever attentive to the public security and welfare, most graciously instituted the Royal Academy of Artillery for the instruction of young gentlemen in the Art of War. As it is my duty, so it has ever been my care, to facilitate their studies: and if my labours should be thought to deserve Your Royal Highness's attention and approbation, it would be an inexpressible satisfaction to me, who think myself happy in every opportunity of shewing the prosound respect with which I am,

SIR,

Your ROYAL HIGHNESS'S

most bumble,

most dutiful,

Woolwich, Sept. 1755.

and most obedient servant,

JOHN MULLER.

PREFACE.

7HEN a fortress is to be built, to choose fuch a fituation as will answer the intent in the best manner, to adapt the works porperly, and to use no more than are necessary, to make from their plans and profils an estimate of the quantity of masonry requisite, and of the earth to be removed, to trace the plan on the ground, to lay the foundation in any kind of foil, to compleat the walls, ramparts, and all the military buildings, fuch as draw-bridges, town-gates, powdermagazines, barracks, store-houses, cazemats, and fally-ports; these are the subjects of Practical Fortification, and what we propose to treat of in the following work, together with the manner of building stone-bridges over large rivers, piers for inclofing harbours, wharfs, quays, fluices, and aqueducts.

As no Treatise of this kind has appeared yet in English, I thought it would not altogether be useless to the public, if I should give, in a plain and easy manner, the construction and executive part of the works belonging to a fortress, and add whatever might contribute to the improvement of this useful art, such as the theories contained in this work, which it has been my endeavour to render as general, and as simple as the nature of the subject will admit of, that they might extend to all the different cases which may occur, and at the same time be with ease adapted to common practice.

It being of importance to know the proper thicknesses of the walls which support earth, so that they may be ftrong and durable, yet not more fo than is necessary; therefore this work begins with a general theory of them; which being deduced from the least exceptionable principles, is applicable in all kinds of foils and cases: for the common supposition made by some gentlemen of the Academy of Sciences at Paris, and by Mr. Belidor, that the natural flope of earth not supported by a wall forms an angle with the horizon of 45 degrees, is true in one particular kind of foil only. This is plain to reason, from the different tenacities of different foils, and may be verified by an easy experiment; which will serve likewise as a practical method for finding the angle formed by the natural flope of any kind of earth.

Make a bank of newly removed earth about ten or twelve feet high, and cut it vertically on one fide; this bank being left standing during eight or ten months in the dampest season, will form the angle required. It is true, the particles of earth being heterogeneous, they will not form an even surface, therefore that angle will vary in different places; but as in practice no geometrical exactness can be obtained, nor is required; if that angle comes within five degrees of the real one, it is sufficient; for that quantity, more or less, makes little difference in the thickness of walls, as may be seen

in the table of general rules. Since then fand causes a greater pressure, and clay a less one, than common earth; to make the walls in each case of an equal strength would endanger those which support sand of falling down, and there would be more work than need be in those which support clay: besides, as stone is specifically heavier than brick, it is evident, that stone walls do not require so great a thickness as those made of brick, yet the gentlemen mentioned before, have made no distinction between the one and the other in their theories.

As some of my readers may not understand algebra, which I have been obliged to use, in order to make the theory general; therefore, to render this work useful to every reader, I have added a table, containing general rules for finding the dimensions of stone and brick walls of any height, according to the different angles made by the natural flope of earth with a vertical fection, from 80 to 30 degrees for every 5 degrees interval, and according to the different flopes given to walls on the outfide. The natural flope of common earth making nearly an angle of 45 degrees, and being the case that most frequently happens in practice; I have computed four tables of dimensions upon this supposition, two for stone walls, and two for brick ones, from ten to fifty feet high, with or without parapets: these tables contain the thicknesses above and below in regard to the different flopes given to the walls on the outfide, together with the dimensions of the counterforts; in order to fave a builder the trouble of computing them himself, although it be very short and easy.

Since fortresses are mostly built at present with demi-revetements, that is, they are partly walled,

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and partly turfed on the outside; I imagined that tables containing the dimensions of this kind of walls would also be very useful, and so much the more acceptable to the reader, as no author has given any before; this was not owing to any belief that they were not useful, but rather to the difficulties in constructing them: for as the height of the walls and that of the earth above them, form an infinite number of cases, to comprehend them all in a table would have been impossible: therefore the only thing that could have been expected was to give tables of their ratio's, as we have done.

That I might omit nothing useful in practice, I have given problems of all the different profils of walls which have hitherto been used upon various occasions; and have compared the quantity of mafonry that each of them requires, in order to know which is preferable to the rest; whereas the French authors, who are the only ones that have written upon this subject, have implicitly followed the profil of Mr. Vauban, as being universally used by all the engineers in France, without confidering whether it might not be changed for another better adapted to the nature of the subject; whereby they have been reduced to the necessity of making their computations fo very operofe as they have done; on the contrary, I confidered that as the sections in the same kind of earth are always similar, by making the profils likewise similar, the operations would become very eafy; fince the thicknesses of those walls which have the same slope would then be to their heights in a constant ratio.

I proceed next to the theory of arches, which is esteemed one of the most difficult problems in me-

chanics;

chanics; for tho' feveral eminent mathematicians have attempted to folve it, yet in my opinion, not one has entirely succeeded; for whoever reads their performances of this kind, will find, whenever their general equations are applied to any particular example, that nothing but absurdities follow from fome, and fuch dimensions from others, as by no means answer the purpose. Some of them have supposed that all the arch-stones were quite smooth and polished, laid without any cement or mortar; and others, that the part of the arch between the key-stone and the hanches was as it were one continued stone, and the other part between the hanches and the spring of the arch, joined to the pier as if all together formed likewise one stone: but as both these suppositions are erroneous, and contrary to what happens in arches, it is evident, that the conclusions drawn therefrom cannot be just.

I have considered the pressure of every arch-stone feparately, both in regard to its weight and the obliquity of its direction, and have supposed them to be laid in fuch mortar, as is neither hard enough to make the arch like one continued stone, nor yet fo foft as that they may slide with ease upon each other: from thence, and some known principles of mechanics, it is eafily proved, that the fum of the pressures of all the arch-stones contained in half the arch is equal to the pressure which the whole weight would make, were it placed in the center of gravity of half the arch; whereby the folution of the problem has been reduced to that of finding the centers of gravity in the several figures of which arches are composed, which centers are found in the most simple and easy manner that the nature

of the subject will admit of; and the solution of the problem, whereby the thicknesses of the piers are found, is contained in a very simple quadratic

equation.

It has hitherto been imagined, though without any foundation, that an elliptic arch is weaker, and presses the piers with a greater force than a circular one: the reason which authors pretend to give for this supposition is, that all the joints of a circular arch when produced meet in the same point; from thence they erroneously conclude, that it is the strongest; without considering that all low arches require less masonry than those which are higher, and that the increase of force against the piers, arising from the obliquity of their directions, is diminished more in proportion by the lesser quantity of weight which they support.

In the problems given of the several kinds of arches, it has been found, that the thickness of the piers are nearly the same in all arches of the same width; though those of circular ones are rather greater than any others, but yet not so much as deserves to be taken notice of. This appears also from the common principles of mechanics; since the highest arches, which are most loaded, have the directions of their pressures less oblique; and on the contrary, the lowest, which are least loaded, have the directions of their pressures more inclined.

This being demonstrated, many difficulties, which often arise in the construction of arches, are easily avoided: as for example, when a powder magazine built in the common manner would become so high as to be seen from without, it may be made with an elliptic arch: when cazemats,

fally-

fally-ports, or any other fubterraneous buildings are to be built under low ramparts, and there is not a fufficient quantity of earth to cover them if the arches were made circular, they may be made elliptic, or with arcs of circles. It is true, that elliptic arches may appear not fo strong in powder magazines as circular ones, and of confequence, less able to resist the shock of the shells thrown upon them: but if it be considered, that they are more curvated at their hanches where they are thinnest, and that the middle of the arch, which is its weakest part, is sufficiently covered by masonry to apprehend no danger there; it will be found that the elliptic arches are full as strong as the circular ones.

But the greatest use of elliptic arches appears to be in the building of bridges, and they seem indeed to be the only ones that are proper for such works: for when the arches are of a great width, the circular form raises the middle of the bridge too high above the ends, whereby the draught of heavy carriages becomes very great, neither does it appear so well to the eye, and requires much more masonry than is necessary; to which may be added, that this great weight requires larger soundations for the piers, and often causes them to sink when the soil underneath is not very hard and solid, as experience has sufficiently shewn.

I do not know what can excuse an architect, who makes use of circular arches in bridges, when it is known that they require so much more masonry than is necessary; since an elliptic arch is as easily described upon boards with a string about two points as a circular arch about one, neither

is there any greater difficulty to trace the joints in one than in the other, nor in the making patterns for cutting the arch-stones: therefore the pretended difficulties which some builders alledge, to be met with in the construction of elliptic arches, are frivolous and trisling, in comparison to the many advantages they have over all others.

If the arches of Westminster-bridge had been made elliptical, and so as that their heights had been two thirds of what they are now; then the gaeat or middle arch, which is 76 feet wide, and 38 feet high, would have been reduced to the height of 25 feet 4 inches only, and the rest in proportion; the quantity of masonry contained in the arches would have been diminished by one third, and the slope above, which is so considerably steep, and makes the bridge appear so disagreeable to the eye, would have become quite easy.

In order to explain the several problems given for different arches, and to make their application plain and easy; I have given examples in numbers of every one, and for the sake of saving trouble to the builders, I have computed a table of dimensions for piers of powder magazines, from 6 to 24 feet high, wherein the shock of the shells that may be thrown upon them has been considered: as these dimensions agree very nearly with those which Mr. Vauban has used in the construction of several magazines; and these magazines have never failed in any siege, though many thousands of shells have fallen upon them, as has been related; the reader may depend upon the dimensions we have given in our table.

The

The third fection contains the theory of timber, a subject of no less importance to an engineer than any of the former; fince thereby he is informed, how to place every piece in its best position, and what dimensions they ought to have, so as the whole frame shall be equally strong in every part, without using more timber than is necessary. After having determined the proportion between the strength of scantlings of the same or different forts of timbers, placed any how, and which have different dimensions; I give several tables of dimensions for girders, joists, principal rafters, and other pieces used in buildings, made of oak or fir, adapted to large and small buildings; and from thence it is shewn, that the dimensions given by architects, bear no just proportion to each other.

As most of ou rarchitects make the oak scantlings of larger dimensions than those of fir, which are to support the same weight; and as Mr. Parent, formerly of the Academy of Sciences at Paris, is faid to have made feveral experiments on the strength of timber, and found that the strength of fir scantlings is to the strength of oak scantlings of the same dimensions, as 6 to 5: I was induced to make some experiments myself, in order to confirm, or shew the falsity of a supposition so improbable. By these experiments I found, that the strength of the weakest oak I tried, was to the strength of the best fir I could get, as 8 to 7, and by comparing the best of each fort, as 3 to 2; which differs greatly from the practice of our architects, and the experiments made by Mr. Parent.

In regard to the practice which I have treated of, in the second and third parts of this work, such

as forming a scheme for building a fortress, the manner of tracing the works on the ground, the preparing and distinguishing the materials, the laying the foundations in any kind of soil, the building the walls and ramparts, together with all the military buildings which fall under the direction of an engineer; we shall refer the reader for these to the table of contents; and only observe here, that nothing has been omitted which I imagined to be of any use to the young and unexperienced engineer.

The fourth and last part treats of aquatic buildings, a subject more copious, and no less necessary
to be understood by an engineer than any yet mentioned: for few fortresses are now-a-days built
but what are situated near navigable rivers, lakes,
or the sea, for the benefit of trade and navigation:
consequently bridges, harbours, sluices, and aqueducts are immediately connected with them, and
are to be built by the same engineer who directs
the works of the fortress; for which reason, I have
endeavoured to assist him as much as the shortness

of the work will admit of.

This part begins with the description of stone-bridges, where, after having treated of their situations, and other previous precautions to be taken before the dimensions are fixed upon; I give a problem for determining the thickness of piers of any height, when the width of the arch is given; and from thence I have constructed a table, containing the thicknesses of piers from 6 to 24 feet high for arches from 20 to 100 feet wide, which no author has yet done: It is true, Mr. Belidor has given a rule for finding the thickness of piers which

are fix feet high: but as this rule ferves in one case only, and is deduced from practice, and not grounded on theory, nor any substantial reasons; it is evident, that no great dependence can be had thereon. Then I describe various methods for laying the foundations, either with batardeaus, coffers, or other contrivances, in different depths of water, and in any kind of soil; and also the manner of carrying on the work from the beginning to the entire finishing the bridge, with all the security and necessary precautions we could think of.

After this I treat of harbours, a subject of great importance in a trading nation like this, to preferve not only the royal navy in stormy weather, but likewise afford an asylum for merchantmen in diffress; though there have been several built in different parts of Europe in later times, yet we are very much in the dark in regard to a method whereby we may proceed in all kinds of fitua-Very few directors of these works have thought proper to communicate their proceedings to the public. Mr. Belidor is the only author who has written particularly upon this subject; but as in most parts of France stones are in great plenty, whereas they are generally very scarce in the greatest part of this country; the method which the French chiefly follow can be but of very little use here: it is true, this author has given several others, that may be used in most situations, which I have taken care to infert in this work, and have added fuch others as I imagined might ferve upon those occasions where his could not be applied.

I have endeavoured to be as particular as possible, in the preliminary enquiries to be made before arefolution is taken to fix upon the spot of ground for making a harbour; as likewise in the choice of the materials to be used; in placing the entrance of the harbour, so as the ships may enter in stormy weather, and sail out when fair; in the manner of laying the soundations in any kind of soil, in that of carrying on the work; and sinally, in examining into the proper thickness which the piers ought to have, in order to resist the waves, and at the same time be convenient for lading and unlading ships whenever it

should be found necessary.

To illustrate what has been faid, I have given the plan and fection of a pier made of stone or brick, together with the plan and fection of one of wood, both which have formerly been proposed for inclosing a harbour to be built at that time. As it was faid that the funds allowed were not fufficient to build the piers with stone, I proposed to lay the foundation only with stone, and to finish the rest with bricks, strengthened at every eight feet high, with a course of stones crampt together; or, if this method was yet too dear, to build the piers with wooden frames, in the manner given here; but an objection was made that brick would foon be deftroyed in faltwater; though it may be proved that when they are well burnt, fuch as those called clinkers, they are more lasting than Portland stone: For at Portsmouth, the foundations on the sea side built with this stone, are made quite hollow, and worn away by the motion of the fea-water; whereas the bricks used at Woolwich wharf, at Chatham dock, and at Dover harbour, besides some others to be met with in Holland, are not the least damaged, though they have been laid thefe many years. What What has been said in respect to laying the soundation, and carrying on the work of piers for harbours, will equally serve for building wharfs, quays, and slips for docks; since the one and the other require a continued wall to be made in water; only wharfs and quays are built with less trouble, on account of being near the shore, where the motion of the water is not so dangerous; and are built but of a single wall, which therefore is made stronger, and secured with land-ties, to prevent its being thrust out by the heavy bur-

thens generally laid upon them.

The work concludes with the manner of building fluices and aqueducts, a subject too copious to be treated so fully as it ought to be in so small a work as this; however, the manner of fecuring the foundation with common and dove-tail piles has been fully explained, as well as that of making the wooden frames and floors which are laid upon them; and how the masonry is to be carried on in the fecurest manner. That the reader may be enabled to proceed upon all the various occasions, which may happen in practice, I have given a general construction of a large fluice with a double pair of gates, in such a manner as to be applicable to the most essential cases, by changing a few particulars, which may vary in certain circumstances; I have likewise shewn how to determine the most advantageous position of the gates, and given the dimensions of the several pieces of which the gates of fuch fluices are composed, whose width are from 8 to 48 feet; as likewise the irons made use of to fix and secure them: in short, nothing effential has been omitted, which might any ways contribute to the reader's fatisfaction.

If it be confidered, that canals for navigation are made from one end of a country to the other, over hills and valleys, by means of fluices and aqueducts; that harbours are formed and cleared from the fand and shingle driven in by the water; low and marshy lands dried and made arable, as likewife dry and barren lands supplied with a proper moisture to make them fruitful; countries are defended against a powerful enemy by forming inundations; towns supplied with water: and if to this we add, the excellent use of sluices in the attack and defence of places, fo well described by Mr. Belidor, whereby a fortress may be made almost impregnable; whoever considers all these things, will find, that no works directed by an enigneer, require a more extensive knowledge, both in theory and practice.

I have endeavoured throughout the whole work to be as distinct as I could, in order to make the subject plain and easy; but as no improvements can be made in any branch of learning without the help of theory, I fear that many of my readers will not understand the most essential parts of this work, which it was not in my power to treat of otherwise; I would therefore advise the learner to begin to study my Elements of Mathematics, which were composed chiefly for military gentlemen, and to serve as an intro-

duction to works of this kind.

As I am sensible, that, for want of being thoroughly acquainted with the English Language, many grammatical errors are to be found in this work, notwithstanding all the possible care that has been taken; I hope for the reader's indulgence in this respect.

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288	28	4	6

N.B. The Numbers as in the Book are conformable to the First Edition of Elem. Math. and those corrected to the New.

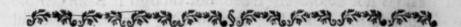
TREATISE

CONTAINING

The PRACTICAL PART

OF

FORTIFICATION.



SECT. I.

The THEORY of WALLS.

N order to have a clear idea of what follows in regard to the theory of walls, it is necessary to explain the suppositions, on which its veracity depends. Thus we suppose that if new made earth, such as in ramparts, was not supported by a wall, the particles would loosen from each other by the dampness of the weather, and tumble down so as to make a slope nearly in a plane surface, which plane is called the natural slope of the earth; and is supposed to have always the same inclination in the same fort of soil.

The second is, that the wall is so well cemented, as if it were made of one single stone, as far as its foundation, so that, if a sufficient power was applied to any part of it, it would break

off near the foundation, and would turn in the same manner as if it was composed of one stone only.

The first of these suppositions may be proved in this manner; since whatever obliquity is required for one particle to tumble down, the same will also be required for any other of the same weight and tenacity, and therefore the sum of all the particles tumbled down, will form a plane surface nearly, which has always the same inclination in the same fort of soil, but will vary according as the soil has a greater or less tenacity. For example, sand will form a greater slope than common earth, and this a greater than loam or clay.

It may be faid, that all the partieles of the fame fort of foil have not the fame magnitude, as may be feen distinctly in fand, and therefore what we have faid is not absolutely true: but though it is impossible to determine this subject according to a methamatical strictness, yet it is sufficiently exact for common practice, where so great a nicety is not required, nor ne-

ceffary.

As to the fecond supposition, if we consider that the wall is always built a twelve month, or ought to be so, before the earth is laid against it, it has time to dry well, before any pressure is made against it; besides small branches of wood are mixt with the earth to lessen its pressure: and though the wall is joined as firmly to its foundation as in any other part, yet this is advantageous to the resistance of the wall; and the supposed equilibrium, between the momentums of earth and the wall, is not strictly true, nor ought it to be so; or else the wall would soon tumble down, by the least accident that would happen.

PROBLEM I.

To find the pressure of earth represented by the triangle CDT, against the profil ABCD, of a wall, in a direction perpendicular to the vertical line DC. Plate I. Fig. 1.

AS the profil ABCD, and the triangle DCT, represent the bases of solids which have the same altitude, the weights of these solids will be proportional to their bases; for which reason we shall consider the areas of the section ABCD, and of the triangle DCT, as so many weights, which are proportional to them. Since the sum of the momentums of all the parts is equal to the momentum of the whole weight re-united into its center of gravity by art. 422 of our Elem.

It is evident that the weight of the triangle DCT, may be considered as re-united into its center of gravity S, and the descent of that center, when the triangle slides along the inclined plane, will be that by which its force against the wall must be estimated. If therefore SR be drawn perpendicular to the side D C of the wall; the whole pressure may be considered as act-

ing against that point R.

Now because the area of the triangle DCT, is equal to ½ DC x CT; if we call T the action of the weight in the direction parallel to the inclined plane DT; and W the part acting in the direction SR perpendicular to DC: we have DT: DC: ½ DC x CT: T; by art. 499 of our Elements; and DT: CT:: T: W, by art. 501: and the compound of these proportions gives DT²: DC x CT: ½ DC x CT: W. Consequently the angle CDT being given, the pressure W will be given likewise.

COR. I.

Hence if the height DC of the wall be called a, DT unity, and CT=s: then will W=\frac{1}{2}ssaa, by the last proportion; and because the action along the inclined plane DT, is retarded by the cohesion of the parts, and it has been found by experiments that a body sliding along a smooth plane, requires one third of its weight to move it; therefore this expression ought to be diminished in the ratio of 3 to 2, in order to get the true pressure: Again, the specific gravity of stone is to that of earth as 3 to 2; so that if we will compare the weight of the triangle DCT of earth with the weight of stone; the expression must be reduced also in that ratio: that is, the value of W must be reduced in the ratio of 9 to 4, in order to get \frac{2}{9}ssaa for the true pressure.

COR. II.

Because the line SR, is parallel to the base AD; DR will express the distance of the direction SR of the pressure against the wall from the base, or the point fix A, about which the wall must turn in order to be overset; and since DR is $\frac{2}{3}a$, by art. 427. the product of the weight $\frac{2}{9}ssaa$, multiplied by the distance $\frac{2}{3}a$, gives $\frac{4}{27}ssa^3$, for the momentum of the earth's pressure.

NB. It may be observed that DT is to CT, as the radius is to the fine of the angle CDT; and therefore, s expresses the fine of that angle, when the radius

is unity.

PROBLEM II.

To find the thickness BC above of a stone wall ABCD, so as to resist the pressure of the earth CDT.

Draw BE perpendicular to the base AD; and let the weights Q, P, be suspended in the centers of gravity of the triangle ABE, and the rectangle EC, and to be

proportional to their areas respectively.

Now because the pressure of the earth endeavours to overfet the wall in the direction SR or DA, whilft the weights Q, P, retain it in the direction perpendicular to AD: the fum of the momentums of the weights Q, P, must therefore be equal to the momentum of the earth's pressure, in case of equilibrio. Hence, if BC or ED=x, and AE=na; the letter n expressing an indetermined but constant quantity; then will $Q = \frac{1}{2} naa$, P = ax; and as the distances of the weights Q, P, directions from the point A, are ? A E, $A \to \frac{1}{2} \to D$; that is, $\frac{2}{3}na$, $n = \frac{1}{2}x$; therefore anna will be the momentum of the weight Q, and naax-1-axx, that of the weight P: the fum of these two momentums being made equal to 4 ss as the momentum of the earth, and both fides divided by $\frac{1}{2}a$, gives $xx + 2 nax + \frac{2}{3}nnaa = \frac{8}{37}ssaa$; by adding innaa to both fides, the first will be a perfect square, whose root multiplied by 9, and the other side by 81, is $9x + 9na = a\sqrt{24}ss + 27nn$.

N. B. Mr. Cotes, in his Hydrostatic lectures, page 61, says that the specific gravity of stone is to that of bricks as 2.5 to 2; that is, as 5 to 4. If therefore we increase the first term 24 ss, under the radical sign in the ratio of 4 to 5, we shall have $9x + 9na = a\sqrt{30ss + 27nn}$, for the equation which determines the

thickness above of brick walls.

For example, if the base of the wall's slope is one fifth of its height, and the slope of earth makes an angle

B 3

of 45 degrees; then will $n = \frac{1}{3} = .2$, nn = .04, and s = .5: whence multiplying 24 by .5 and 27 by .04 and extracting the square root of the sum 13.08, we get 3.6167, from which substracting 1.8, and the difference divided by 9, gives x = .2018 a, or $x = \frac{1}{3} a$ nearly in stone walls. But if 30 be multipled by .5, and added to 1.08; the square root of 16.08, will be 4.009 nearly; from which substracting 1.8, and dividing the difference by 9, we get x = .245 a nearly in brick walls.

Of COUNTERFORTS.

IN building walls that are to support earth, buttresses are made behind them at certain distances from each other, which are not seen, as being covered with earth; they are made in view to strengthen the wall against the pressure of earth, and to save expences; for by this means there is no occasion to make the walls so thick as they otherwise must be. These buttresses, are called Counterforts, in fortification, and are made of various forms.

Plate I. Fig. 2. Suppose the trapezium ABCD to represent the section of a wall without parapet; then the rectangle DF represents the elevation of the Counterfort, which is generally as high or within a soot, as the wall, and the base DG the length; and if we consider the plane of the wall; where KLMN, represents the base of the Counterforts, and NP, their distance from each other, which may vary at pleasure.

Mr. Vauban made the base KLMN of the counterforts always broader at the root KN than at the tail LM, in the constant proportion of three to two; and the distance from the center of one to that of the next, 18 feet: On the other hand, Mr. Belider would have them made the contrary way, that is, narrower at the root KN than at the tail LM in the same in verse proportion of two to three; because the center of gravity of the counterfort, being thereby farther from the wall, will support a greater weight, than those made

by Mr. Vauban; they are besides not so easily destroyed by cannon, when the wall is beat down, and so keep better up the earth. But as he imagined that the engineers would hardly change an old established practice, for any other ever so advantageous; he computed his tables according to Mr. Vauban's profil.

We, on the contrary, make the base of our counterforts rectangular, partly because our engineers make them so, and because they are very near as strong as those made by Mr. Belidor; they likewise bind better with the wall, and the workmanship is cheaper and easier; so that in the mean, they are better than those

of any other form.

Instead of placing the counterforts at the same distance, whether the wall is high or low, as Mr. Vauban does, we make their thickness K N to their interval N P always in the constant ratio of unity to three, and their length K L or D G, one fourth of the height D C of the wall. From this disposition of the counterforts, the profils become similar, and their thickness BC above is in a constant ratio, with the height D C, when the slope A B remains the same; as will be seen hereafter; whereby the operations become extremely easy. And this rule is agreeable to the pressure of the earth, which we have shewn above to be similar in the same fort of soil.

In a wall of ten feet high, the counterforts, according to Mr. Vauban's general profil, are 3 feet thick and at 15 feet distant from each other; and in a wall of 80 feet, their thickness is 10 and distance but 8; and therefore his counterforts are too far distant in low walls and too near in high ones; whereas ours may be placed farther from or nearer to each other, according as it is convenient in practice, provided the proportions mentioned above are observed.

It may be observed, that the longer the counterforts are the greater force they have to resist the pressure of the earth; but when they are made to narrow, they do

B 4

not bind so well with the wall; for which reason, I would make their thickness never less than half their length. For instance, in a wall of 40 feet high, the length of the counterforts will be 10 feet, according to the proportion mentioned before: their thickness ought, in my opinion, to be no less than 5 feet, and then their distances from each other will be 15 feet; but in a wall of ten feet high, their length will be two feet six inches; and their thickness ought to be two feet; then their interval will be six; whereas if they were made thinner, they would stand too close to one another.

PROBLEM III.

To find the thickness above, of stone walls which have counterforts, so as to resist the pressure of the earth. Fig. 2.

Because the length DG of the counterforts is a fourth part of the height DC; the area DF will be $\frac{1}{4}$ a a, and AD $+\frac{1}{4}$ DG, that is, $x + na + \frac{1}{8}a$, will be the distance of its direction from the point A; therefore $\frac{1}{4}aax + \frac{1}{4}na^3 + \frac{1}{32}a^3$, will be the momentum of the counterfort: but as there is an interval between them, and therefore is too much by that interval, or as but one part in four is taken up by the counteforts, this momentum must be divided by 4 in order to have $\frac{1}{16} a a x + \frac{1}{16} n a^3 + \frac{1}{138} a^3$, for the true momentum; which being added to that of the wall found in the last problem, and their sum made equal to that of the earth, when divided by \(\frac{1}{2} \) a, gives, \(\times \) $+2.nax + \frac{1}{8}ax + \frac{2}{3}nnaa + \frac{1}{8}naa + \frac{1}{64}aa = \frac{8}{27}$ ssaa: if we add innaa - 75 aa to both fides, the first will be a perfect square, and the second reduced under the same denomination, whose common denominator is 81 x 64; then the first side multiplied by its root 72, gives $72x + 72na + 4.5a = a\sqrt{1536}ss -$ 60.75 + 1728 nn for the general equation which determines the value of x in stone walls: But if we increase the

the first term 1536 ss under the radical sign, in the ratio of 4 to 5, as has been shewn in the last problem, we get $72 \times + 72 \times n + 4.5 = a\sqrt{1920} \times 5 - 50.75 + 1728 \times n + 1728 \times n$, for the general equation which determines the value of x, in brick walls.

Hence it is manifest, that when the fine s, and the value of n are known, the thickness above x of the wall, will be always expressed by parts of a, the height of the wall; and from thence, general rules may be found for all the different slopes that commonly are given to walls, and for any angle the slope of earth makes with the vertical line D C, as will appear by the

following examples.

Let the base A E of the slope be one fifth of the height D C, and C D T an angle of 45 degrees: then will $n = \frac{1}{3} = .2$, and $ss = \frac{1}{2}$; these values being substituted into the first equation gives 776.37 for the quantity under the radical sign, whose square root is 27.863a; from which subtracting the sum 18.9 a, of the two known terms, and dividing the difference by 72, we get x = .1245a, or $x = \frac{1}{8}a$ nearly in stone walls.

But if we substitute the values of ss an n, into the second equation, we get 968.37 for the sum of the terms under the radical sign, whose square root is 31. 118a, from which subtracting the sum 18.9a, of the two known terms, and dividing the difference by 72.

we get x = . 169 a, in brick walls.

If the base A E of the slope is one sixth, and the angle CDT, 45 degrees: then will n equal $\frac{1}{6}$, $ss = \frac{1}{2}$; these values being substituted into the first equation gives 755.25 for the sum of the terms under the radical sign, whose square root is 27.481a, from which subtracting the sum 16.5a of the two known terms, and dividing the difference by 72, we get x = .153a, in stone walls.

But if the same values of n and s s, are substituted into the second equation, we get 947.25, whose square

root is 30.777a, from which subtracting the sum 16. 5a of the two known terms, and dividing the difference by 72, gives x = .198a, in brick walls.

Again suppose the angle of the slope D T to be 30 degrees, then will s = .5; and ss = .25: these values being substituted into the first equation, give 384, for the first term under the radical sign, and by substituting that value in the second equation, we get 480 for that term.

Now if n = .2; we get 392.37 for the fum of the terms under the radical fign, whose square root is 19. 808, and hence n = .013a, nearly in stone walls; and in brick walls, we get 488.37 for the quantity under the radical fign, whose square root is 22.099, and hence n = .044a nearly.

Because the sum of the squares of the sine and cosine of any angle is equal to the square of the radius; if we subtract the square .25 of the sine of 30 degrees, from the square of the radius or unity, we shall have .75 for the square of the sine of an angle of 60 degrees.

Whence, substituting this value into the first equation, we shall have 1152 for the first term under the radical sign, and by substituting the same value into the second, we get 1440 for the first term under the radi-

cal fign.

Now if n=.2; then will 1160.37 be the fum of the terms under the fign, whose square root is 34.064, and hence x=.211a, in stone walls, and 1448.37, will be the sum of the terms under the sign, whose square root is 38.057: and therefore x=.266a, in brick walls. When the slope of earth DT makes any other angle, the operations become more tedious; and in that case the values of s, are to be taken out of the tables of natural sines; and it will be sufficient to take only the three first numbers.

But to fave the trouble to practical engineers, we have computed the values of x, when the flope is \(\frac{1}{5}, \frac{1}{6}, \)
\(\frac{1}{7}, \frac{1}{4}; \) for both stone and brick walls; and when the flope

flope D T of earth makes an angle from 30 to 80 degrees for every 5 degrees, which we imagine to be sufficient, as may be seen in the following table, where the fractional numbers in the first horizontal line express the ratiop of the base A E of the wall's slope to the height of the wall; the first vertical column shews the angles which the slope of earth makes with the vertical line DC: and the other numbers give the ratio of the thickness of the wall; or the values of x, to its height, which numbers are all decimals.

Example, If the base A E of the slope is one sisth of its height, and the angle CDT, 45 degrees; then the number opposite to 45 and under \(\frac{1}{3}\), is 125, which being multiplied by the height of the wall, suppose 30 feet, gives 3.750, or 3 feet 9 inches: suppose the angle CDT, to be 60 degrees, and the base of the slope one sisth; then the number 211 opposite to 60 and under \(\frac{1}{3}\), being multiplied by the height of the wall 30 feet, gives 6.330 or 6 feet 4 in-

ches nearly.

N. B. It must be observed once for all, that we always take the nearest number in all our computations. Thus if the fourth decimal is either 5 or above we always increase the third by unity; the same thing is to be observed in regard to inches: for in the last example .33, multiplied by 12, gives 3.96 inches, which

is 4 inches nearly.

GENERAL RULES

For Stone walls.

For Brick walls.

Ang.	5	6	7	8	1 5	. 4.5	1 7	1/8
80°	275	1304	326	342	338	368	389	406
75	265	292	316	332	327	356	378	395
70	250	280	301	317	311	340	362	378
65	235	262	283	299	290	320	342	358
60	211	239	256	277	266	296	314	333
55	191	214	235	251	238	267	288	304
50	153	185	202	221	205	230	251	271
45	125	153	173	189	169	198	219	235
40	089	117	137	153	130	159	179	195
35	052	079	093	114	087	116	134	152
30	013	038	.057	072	044	071	090	106

As the base of the slope is never less than one eighth nor greater than one fifth of the wall's height; we thought it needless to carry these general rules any farther, which however may be done by means of the two preceeding equations, whenever it is thought necessary.

To find the general rule for any intermediate angle fay, As 5 degrees is to the difference between the given angle, and that next to it in the table, so is the difference between the numbers in the table opposite to the angles next below and above the given angle; the fourth term added to the nearest number if above it, or substracted if below, gives the number sought. Thus the angle being 53: substract it from 55, substract the number 153 of 50 from the number 191, which gives 38. Then say, 5: 2::38: 15; and 15 substracted from the number opposite to 55, which is 191 gives 176 for the number sought.

The

The first and second tables have been computed from the general rules, when the slope of earth makes an angle of 45 degrees, which is most commonly the case in a middling soil, and is what Mr. Belidor and others have supposed; so that if any error should have been committed in these tables, they may be corrected by the last rules, and if the height of a wall, not expressed in these tables, should be given, whose thickness above being required, it may be found. Thus if the given height be 35 feet, and the slope one sisth; multiply that height by 125, which gives 4.375 feet or 4 feet and 4.5 inches for the thickness required in a stone wall.

The thickness near the foundation, is found by adding the base of the slope to the thickness above; thus when the base of the slope is one sisth, and the wall 30 feet heigh, then one sisth of 30 is 6, to which add the thickness above 3 feet 9 inches, and the sum 9 feet 9 inches will be the thickness required. It is to be observed that the length of the counterforts, in these tables, is always one forth of the wall's height as has been mentioned before, and their thickness is to their interval as unity is to 3.

PROBLEM IV.

To find the thickness of walls which have parapets, according to the third profil. Fig. 3.

In walls with parapets, the flope A B of the wall is always terminated by the cordon B, within four feet of the top F, and the upright wall BFHI, never exceeds three feet in thickness; and the part H I, is always terminated by the line DC produced, when BC does not exceed three feet.

If the upright part I F of the wall was sufficient to resist the pressure of the earth, above the line B K produced; there need be no other tables than those already

already given; but as this is not the case; the pressure of the earth above the line BK should be computed as well as the resistance of the wall IF, in order to have the true solution of the problem: But this would make the work more tedious, than is necessary in practice, and therefore we shall estimate this force in an easier manner, and which answers full as well.

Suppose the wall ABCD to be carried up quite to the top F, and so as to be sufficiently strong to resist the pressure of the earth, and from thence the thickness at BC is to be found; then I say, that the strength of the whole wall will be sufficient to resist the pressure

of the earth.

For the earth above the line BC, extends not above 18 feet, that is very little farther than the parapet FN reaches; and therefore the part IF of the wall will nearly be sufficient to resist the pressure of that earth; and as BC is more than it should be, were the earth no higher than BC, it is plain that the wall thus determined will resist the pressure of the earth more than is sufficient: besides this agrees perfectly well with Mr. Vauban's profil of 30 feet high, that has been used in above 50 places without having ever failed.

Now because the height BE is to the base E A of the slope as the height BF, or 4 feet, is to the difference between the thickness at B and that at F; that is, as AE is = na, BE = a; we have a: na: 4:4n = to the difference required, which therefore being added to the thickness at F, found in the preceding tables, answering to the height E F, gives the thickness B C

required.

GENERAL RULES.

If the base A E is one fifth of the height B E; then an becomes .8 or 9.6 inches, which is to be added to the thickness in the second Column.

If A E is one fixth of B E, than will 4 n become & or 8 inches, which is to be added to the thickness in the fourth column.

If AE is one seventh of BE; then will 4 n become

in the fixth column.

Lastly, If A E is one eighth of B E; than 4 n becomes 4, or 6 inches; which is to be added to the thickness in the eighth column.

By these general rules the third and fourth tables have been constructed, the lengths of the counterforts in the tenth column, are the fourth part of the total height; though they are never carried higher than the cordon: But it must be observed, that the numbers in the first column, express the heights, from the foundations to the cordon B only; because the height BF, of the upright part is always 4 feet in all walls what-

foever, that have parapets.

To shew by a few examples how the preceding general rules are applied; we shall suppose the height EB of a stone wall to be 30 feet, and the base AE one sifth of that height: then adding 4 feet to 30 we get 34 feet for the total height EF; and the thickness found in the second column of the first table; answerting to 34 feet, being 4 feet 3 inches; to which adding 9.6 inches by the first rule, gives 5 feet and .6 of an inch, for the thickness required. Mr. Vauban makes this thickness 5 feet; so that ours does not exceed his but by half an inch nearly.

If a stone wall is 24 feet high, and the base of the slope on sixth; then 4 feet added to 24 gives 28 feet; and the thinkness answering to this height in the fourth column of the first table is 3 feet 6 inches; by adding 8 inches according to the second rule; then the sum 4 feet 2 inches will be the thickness at B C required.

Thus we have given tables not for stone walls only, but likewise when they are built with brick; and their

constructions are deduced from the morst simple principles, and at the fame time the most general that could have been thought of, and those general rules we have given for the different angles the flope of earth makes, are of excellent use in practice; for it is eafily perceived, that when the foil is of a strong nature. fuch as loam or clay, a great deal of masonry may be faved, and when the foil is fandy, how to proceed with method and fafety, which cannot be done without them. or by guess only.

PROBLEM V.

To find the thickness above, of a stone wall which supports a parapet of earth above it, according to the fourth profil. Fig. 4.

We shall for conveniency fake, suppose the slope CG of earth to be parallel to DH, that which the earth forms; though this is not always the case in practice, yet the difference arising from thence is inconsiderable.

Let the vertical line D C produced, meet the horizontal one GH in F; if DC = a, DF = b, and the rest as before; then if from the momentum of the triangle DFH, which has been found in Cor. 2. after the first problem to be $\frac{4}{37}$ s s b^3 , we subtract the momentum of the triangle CFG, we shall have the momentum of the earth.

Now as CF = b - a; the preffure of that triangle will be $\frac{2}{9} \times 55 \times b - a^2$, by Cor. 1. after the first problem; and fince the diffance of the line of direction drawn from the center of gravity of this triangle perpendicular to DF, from the point fix A, is DC+ $\frac{2}{3}$ CF, or $\frac{a+2b}{3}$; and the product of this diffance multi-

plied by the weight, gives $\frac{2}{27}$ ss $\times 2$ $b^3 - 3$ $abb + a^3$ for the momentum of that triangle; which therefore being subtracted from $\frac{4}{27}ssb^3$, gives $\frac{2}{37}ss\times 3abb-a^3$. Now

Table I. Containing the Dimensions of Stone Walls without Parapets according to the first Profil

		A STATE OF THE STA					0		
	When the	Slope is \$	Whenthe	Ropeist	Whenthe	Stopeist	When the	Stopeist	page
heigh	Thickn. above	Thickn. below	Thickn. above	Thickn: below	Thickn	Thickn. below	Thickn above	Thickn below	Lengt of glountf.
Feet 10	F^{c} In. I : 3	F^{t} In: $3:3$	F. In:	F. In. 3: 2	F! In. 1:9	F. In. 3: 2	F. In.	F^{t} In. $3:2$	F! In. 2: 6
12	1:6	3:11	1:10	3:10	2:1	3:9	2:3	3:9	3:0
14	1:9	4:7	2:2	4:6	2:5	4:5	2:8	4:5	3:6
16	2:0	5:2	2:5	5:1	2:9	5:0	3:0	5:0	4 : 0
18	2:3	5:10	2:9	5 : 9	3:1	5:8	3:5	5:8	4:6
20	2:6	6:6	3:0	6:4	3:6	6:4	3:10	6:4	5:0.
24	2:9	7:2	3:4	7:0	3:10	7:0	4:2	0:11	
26	3:0	8:5	3:8	8 14	4:2	8:2	4:7	8:2	6:0
28	3:6	9:1	4:3	9:0	4:10	8:10	5:4	8:10	7:0
30	3:9	9:9	4:7	9:7	5:2	9:5	5:8	9:5	7:6
32	4:0	10:5	4:11	10:3	5:6	10:1	6:1	10:1	8:0
34	4:3	11:1	5:2	10:10	5:10	10:8	6:5	10:8	8:6
36	4:6	11:8	5:6	11:6	6:3	11:5	6:10	11:4	9:0
38	4:9	12:4	5:10	12:2	6:7	12:0	7:3	12:0	9:6
40	5:0	13:0	6:1	12:9	6:11	12:7	7:7	12:7	10:0
42	5:3	13:8	6:5	13:5	7:3	13:3	7:11	13:2	10:6
44	5:6	14:4	6:8	14:0	7 : 7	13:10	8:4	13:10	11:0
46	5:9	14:11	7:0	14:8	7:11	14:6		14:6	11:6
48	1	15: 7	7:3	15:3	8:4	15: 2		15:1	12: 0
50	6:3	16:3	7:7	15:11	0 . 0	15:10	9:6	15:9	12:0

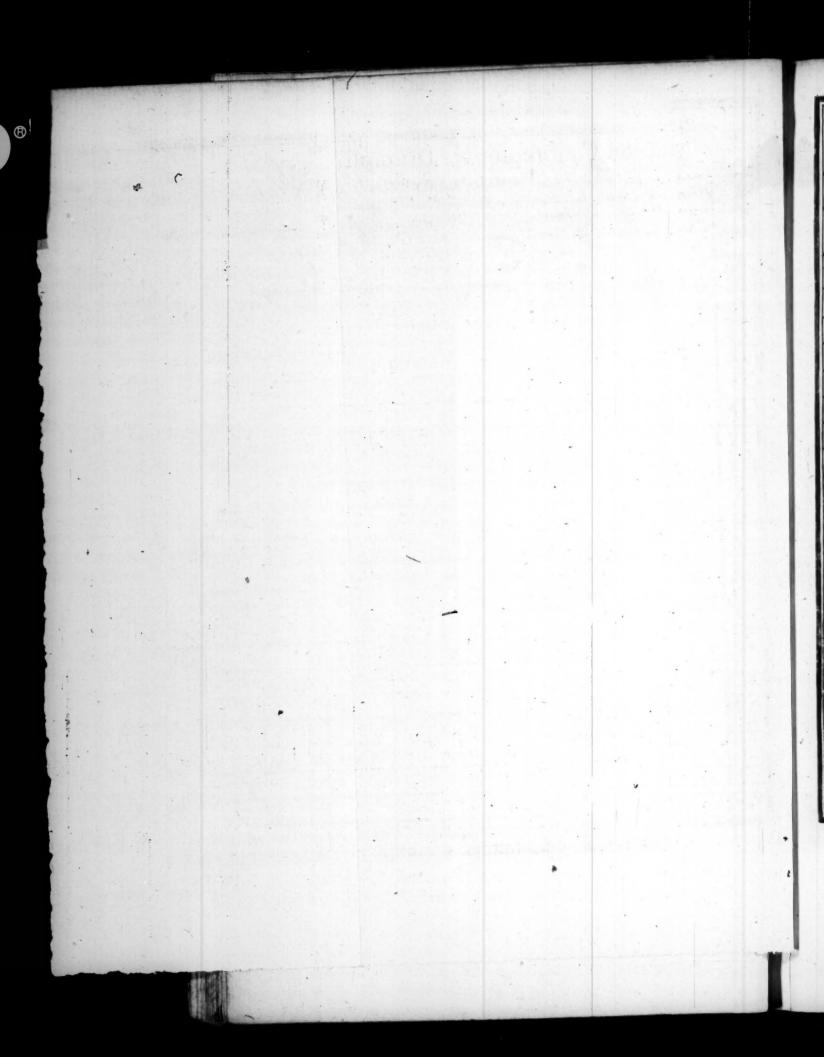


Table II Containing the Dimensions of Brick Walls without Parapets according to the first Profil

n de	When the	Slopeist	When the.	Stopeis &	When the	Stopeist	When the.	Stopeis &	pag.
height	Thickn.	Thickń below.	Thickn above	Thichn below	Thickn	Thickn. below	Thickn't above	Thickn. below	Leng of
Feet 10	F. In. 1 : 8	F^{t} In: $3:8$	F.t In. 2 : 0	F. In. 3: 8	F. In 2 2	3: 7	F! In. 2:4	F^{c} In. $3:7$	Ft In.
12	2:1	4:6	2 : 5	4:5	2 : 8	4:4	2:10	4:4	3:0
14	2:5	5:3	2:10	5:2	3:1	5:1	3:3	5:0	3:6
16	2:9	5:11	3:2	5:10	3:6	5:9	3:9	5:9.	4:0
18	3:1	6:8	3:7	6:7	3 : 11	6:6	4:3	6:6	4:6
20	3:5	7:5	4:0	7:4	4:5	7:3	4:8	7:2	5:0
22	3:9	8:2	4:5	8:1	4:11	8:1	5:2	7:11	5:6
24	4:1	8:11	4:10	8:10	5:3	8:8	5:8	8:8	6:0
26	4:5	9:7	5:2	9:6	5:9	9:5	6:1	9:4	6:6
28	4:9	10:4	5:7	10:3	6:2	10:2	6:7	10:1	7:0
30	5:1	11:1	6:0	11:0	6:7	10:10	7:0	10:9	7:6
32	5:5	11:10	6:5	11:9	7:0	11:7	7:6	11:6	8:0
34	5:9.	12:7	6:10	12:6	7:6	12:4	7:11	12:2	8:6
36	6:1	13:3	7:2	13: 2	8:4	13:1	8:5	12:11	9:0
38	6:5	14:0	7: 7	13:11	8:4	13:9		0	9:6
40	7: 2	15:7	8:5	14:8	9:3	14:6	9:5	14:5	10: 6
	7:6	16:4	8:10	16: 2	9:8	15:11	10:4	15:10	11:0
46	7:10		9:2	16:10		16:8	10:10	16:7	11:6
48	8: 2	17:0	9:7	17: 7	10:1	17:5	11:3	17:3	12: 0
50	8:6	18:6	10:0	18:4	11:0	18:2		18:0	12: 6

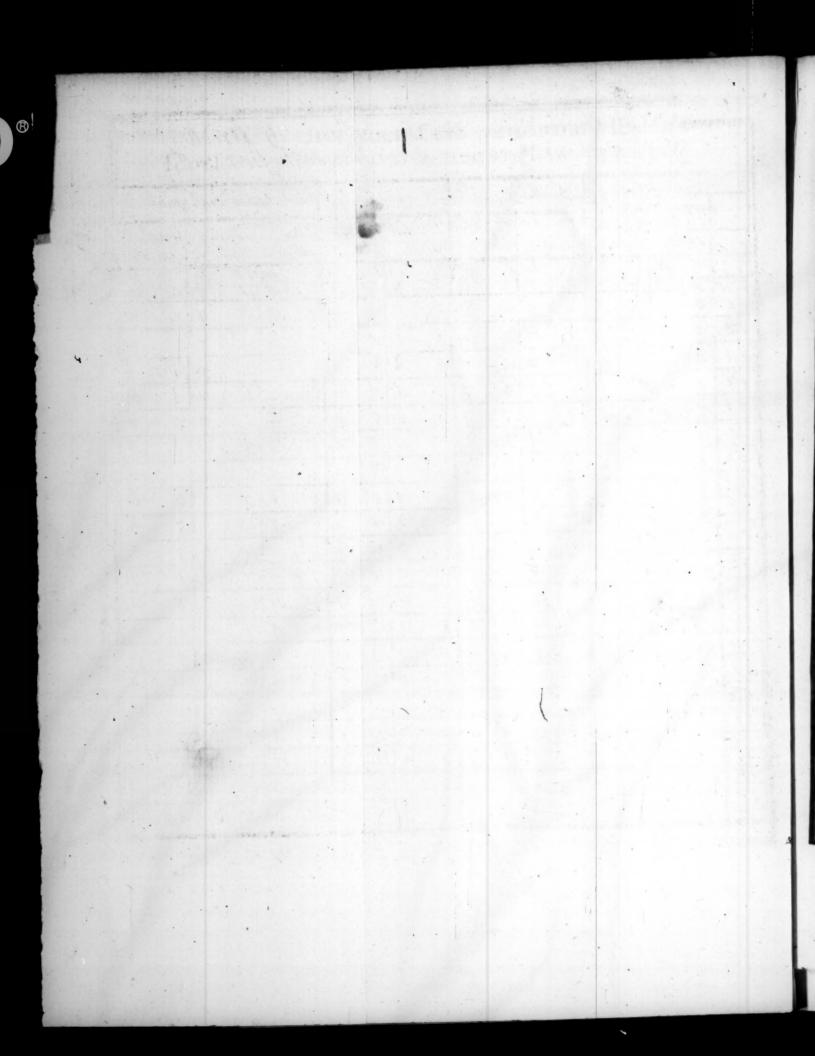


Table III Containing the Dimensions of Stone 2 Walls with Parapets, according to the Second Profil

	Whenthe	eStopeis &	Whenthe	Stopeist	Whenthe	Stopeis +	Whenthe	Stopeist	pag		
height	Thickn. above	Thickri. below	Thickn above	Thickń. below	Thickn. above	Thickn. below	Thickn. above	Thickn'. below	Length of y'lounts.		
Feet 10	F. In. 2: 7	F^{c} In. $5:5$	F. In. 2: 10	F^{c} In. $5:2$	P^{ϵ} In. $3:0$	F. In. 5: 0	F^{ε} In: $3:2$	F. In. 4: 11	F. In. 3:6		
12	2:10	6:0	3:1	5:9	3:4	5:7	3:6	5:6	4:0		
14	3:1	6:8	3:5	6:5	3:8	6:3	3:11	6:2	4:6		
18	3:4	7:4	3:8	7:0	4:1	6:11	4:4	6:10	5:0		
20°	3:10	8:8	4:4	8:4	4:9	8:2	5:*	8:1	6:0		
22	4:1	9:3	4:7	8:11	5:1	8: 9	5:5	8 ; 8	6:6		
24	4:4	9:11	5:0	9:8	5:5	9:5	5:10	9:: 4	7:0		
26	4:7	10:7	5:3	10:3	5:9	10:0	6:2	9:11	7:6		
28	4:10	11:3	5:7	10:11	6:1	10: 8	6:7	10:7	8:0		
32	5:1	12:6	5:10	12: 2	6:10	11:3	7:4	11: 10	9::0		
34	5:7	13: 2	6:6	12:10	7:2	12:7	7:9	12:6	9:6		
36	5:10	13:10	6:9	13:5	7:6	13:2	8:1	13:1	10:0		
38	6:1	14:6	7:1	14:1	7:10	13:10	8:5	13: 8	10:6		
40	6:4	15: 2	7 4	14:8	8:2	14:5	8:10	14: 4	11:0		
42	6:7	15: 9	7:8	15:4	8:6	15:1	9:3	15:0	11:0		
46	7:1	17:1	8:4	16:8	9:3	16:5	10:0	16:3	12:6		
48	7:4	17:9	8:7	17:3	9:5	16:10	10:4	16:10	18:0		
50	7:7	18:5	9:0	18:0	9:10	17:6	10:9	17:6	13:6		

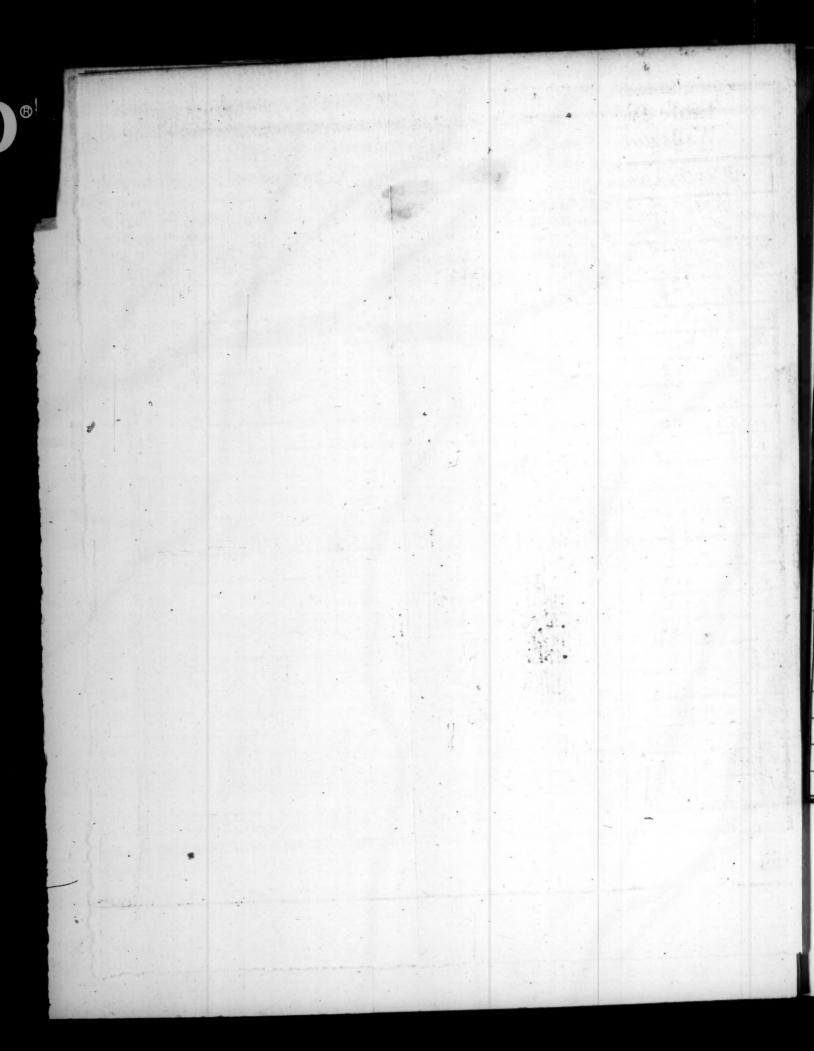
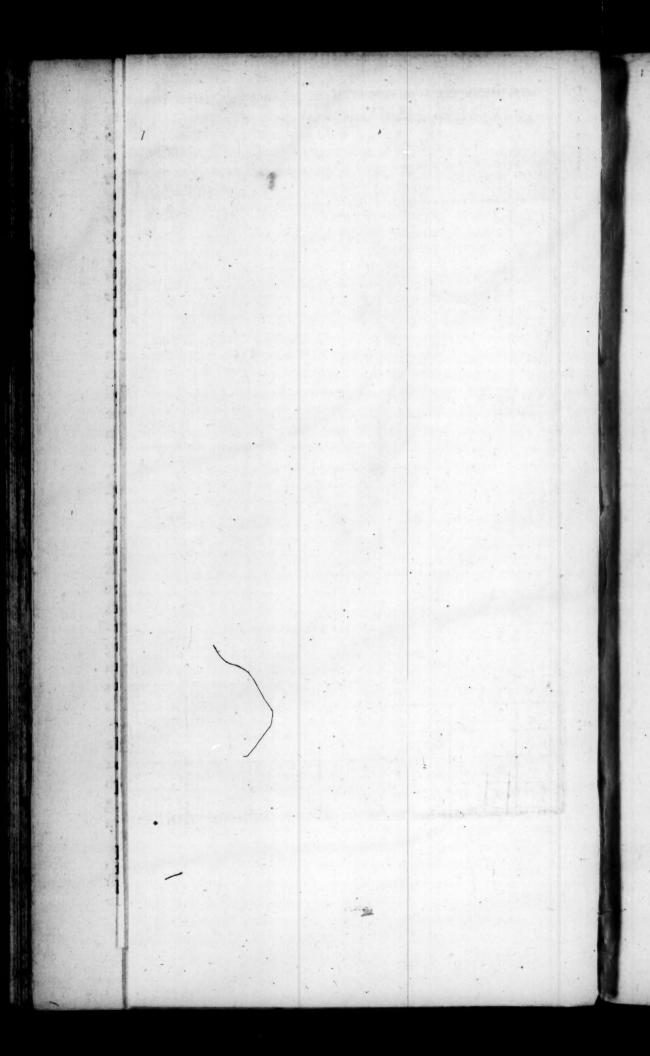


Table IV. Containing the Dimensions of Brick Walls with Parapets according to the Second Profil

			, 1			/-			
	Whenthe	Stopeis \$	Whenthe	Slopeis &	Whenthe	Stope is †	When the	Stopeis &	pag.
height	Thickn! above	Thickn. below	Thickn.	Thickn. below	Thickn. above	Thickn. below	Thickn. above	Thickn. below	Length of Gounts.
Feet 10	F: In. 3: 2	F. In: 5: 11	F: In. 3: 6	Ft In. 5: 10	F^{C} In. $3:8$	F^{e} In. $5:8$	F^{t} In $3:9$	F. In. 5 : 6	F. In. 3: 6
12	3:6	6:8	3:10	6:6	4:7	6:4	4 : 3	6:3	4:0
14	3:10	7:5	4:3	7 : 3	4:6	7:1	4:9	7:0	4:6
16	4:2	8:2	4:8	8:0	5:0	7:10	5:2	7:8	5:0
18	4:6	8:11	5:1	8:9	5:6	8:8	5:8	8:5	5:6
20	4:10	9:8	5:6	9:6	5 :10	9:3	6:2	9:2	6:0
22	5:3	10:5	5:10	10: 2	6.:4	10:0	6:7	9:10	6:6
24	5:.7	11:2	6:3	10:11	6:9	10:9	7:1	10:7	7:0
26	5:11	11:11	6:8	11:8	7. : 2	11:5	7:6	11:3	7:6
28	6:3	12:8	7:1	12:5	7:7	12: 2	8:0	12:0	8:0
30	6:7	13:5	7:6	13:2	8:1	12:11	8:5	12: 8	8:6
32	6:11	14:1	7:10	13:10	8:6	13:8	8:11	13:5	9:0
34	7:3	14:10	8:3	14:7	8:11	14:4	9:5	14. 2.	9:6
36	7:7	15:7	8:8	15:4	9:5	15:1	9 : 11	14: 11	10:0
38	7:11	16:4	9:1	16:1	9:10	15:10	10:4	15:7	57.53
40	8:2	17:0	9:6	16:10	10:3	16:0	10:10	16:4	11:0
42	8:7	17:9	9:10	17:6	10:8	17:3	11:4	17: 1	12:0
44	8:10	18:5	10:3	18:3	11:2		11:9	17:9	12:6
46	9:4	19:4	10:8	19:0	11:7	18:9	12:3	19: 3	13:0
48	,	20:1	11:1	20:6	12:0	19: 5	12:9	19:11	13:6
50	10:0	20.9	" . 0	-0.0	12.3	-0.	10	.9	.0



Now because the momentums of the wall and counterfort are the same here as in the third problem, if we divide the momentum of earth by $\frac{1}{2}a$, and multiply by 3×64 , we get $768 \text{ ss} \times 3 \text{ bb} - aa$ which being substituted instead of the first term under the radical sign in the equation of that problem we get 72×4 $72 \times 4 + 4.5 = \sqrt{768} \text{ ss} \times 3 \text{ bb} - aa - 60.75 aa + 1728 nnaa$, for the equation which determines the unknown quantity x in this case.

When F C becomes = 0, that is when there is no parapet of earth above the wall; then will a = b, and the last equation becomes the same as that in the third

problem.

If the base A E of the slope is one fifth of the height E B; and the angle C D H 45 degrees; then will n = .2 and ss = .5: and the equation above becomes $72 \times + 18.9 = \sqrt{1152 bb} - 375.63 aa$, in this case; but if the base A E be one sixth of the height B E, and the angle C D H, the same as before, we get $72 \times + 16.5 a = \sqrt{1152 bb} - 396.75 aa$.

By means of these two last equations, the fifth and sixth tables have been constructed, which contain the ratio's between the height of walls and their thickness above: they shall be explained by a few examples.

Let the height of a stone wall be to that of the earth above it as 3 to 2; then because $3:2:a:\frac{1}{3}a=$ CF, we get $a+\frac{2}{3}a=\frac{5}{3}=b$; whose square being multiplied by 1152 gives 3200; from which subtracting 375.63, and extracting the square root of the difference, we get 53.144, from which subtracting 18.9 and dividing by 72, gives x=.476a nearly, in the first case.

But if we subtract 396.75 from 3200, and extract the square root of the difference, we shall have 52.945; from which 16.5 being subtracted, and the difference divided by 72, gives x = .506a nearly, in the second case.

If

If the height of the wall is to that of the earth above it, as 4 to 3; then will $b = \frac{7}{4}a$; this value being substituted into 1152 b b, gives 3528, from which taking 375.64, and extracting the square root of the remainder, we get 56.145; if we take 18.9 from this and divide the remainder by 72, we shall have x = .517 a nearly, in the first case.

But if we subtract 396.75 from 3528 and extract the square root of the difference, we get 55.975; from this subtracting 16.5 and dividing by 72, we shall

have x = .548 a nearly, in the fecond case.

If the walls are built of brick, then by what has been faid at the end of the second problem, we have no more to do than to increase the first term under the radical sign, in the ratio of 4 to 5; then the general equation above, becomes that for brick walls. Whence, if the base A E of the slope is one fifth of the height B E, and the angle C D H, 45 degrees; then will n = .2, ss = .5; and $72x + 18.9a = \sqrt{1440bb} - 471.63aa$, will be the equation in this case: and if that base be one sixth of the height B E, and the angle C D H, the same as before, we have $n = \frac{1}{6}$, ss = .5: and therefore $72x + 16.5a = \sqrt{1440bb} - 492.75aa$ will be the equation.

Let the height of the wall be to that of the earth above it as 5 to 2; then will $b = \frac{7}{3}a$, whose square multiplied by 1440 gives 2822.4, from which subtracting 471.63, and the square root being extracted, gives 48.484, and taking 18.9 from this, the remainder divided by 72 gives x = .411a, nearly in the first

case.

But if we subtract 492.75 from 2822.4 and extract the square root of the difference, we get 48.266 and 16.5 being taken from it; the difference divided by 72 gives x = .441 a, nearly in the second case.

gives

Explanation of the following TABLES.

The fifth and fixth, contain the ratio's between the heights of stone walls and their thickness above, when there is a parapet of earth above them; the base of the slope being one fifth and one sixth of the height of the wall; and the slope of earth makes an angle of 45 degrees; the ratio's between the height of the wall to that of the earth above it, are marked in the first horizontal line and column: the length of the counterforts being one fourth of the walls height, and their thickness is to the interval between them, as unity to 3, that is the same as before: The seventh and eighth tables contain the same ratio's when the walls are of brick.

Their uses are as follows: when the height of the wall is given, as well as that of the earth above it, reduce the ratio to its lowest term; look in the first column for the antecedent, which is always supposed to express the height of the wall, and for the consequent in the first horizontal line, then the number opposite to the first, and under the second, expresses the ratio between the height of the wall to its thickness above. This number being multiplied by the height of the wall, and the three last figures taken as decimals, gives the thickness required.

Example, Let the height of a stone wall, whose slope is one sifth, be 20 feet, and that of the earth above it 12: then because 20 is to 12 as 5 is to 3; look in the first column of the fifth table for 5, and in the horizontal line for 3: then the number 442 opposite to the first, and under the second, being multiplied by 20, the height of the wall, gives 8.84 or 8 feet 10 inches nearly for its thickness above.

If the height of a stone wall, whose slope is one fifth, be 13 feet, and that of the earth above it 6: then in the same table, the number 371 opposite to 13 and under 6, multiplied by 13, the height of the wall,

gives 4.823 or 4 feet 9 inches nearly for the thickness above.

But if the flope is one fixth, look into the fixth table opposite to 13 and under 6, and you will find 403, which being multiplied by 13, gives 5.239 or 5 feet 3 inches nearly. We have not inserted the thickness of the walls near the foundation; because they may be found by adding the base of the slope to the thickness above.

N. B. Those squares which are marked with a point only, are opposite to such ratio's as have been determined before, and therefore it would have been needless to repeat them. Thus the ratio of 2 and 2, of 3 and 3, of 6 and 6, &c. is the same as that of unity to unity; and it is the same in respect to all other equal ratio's.

PROBLEM VI.

To find the thickness above BC of a wall when the counterforts have a slope as FG. Fig. 5.

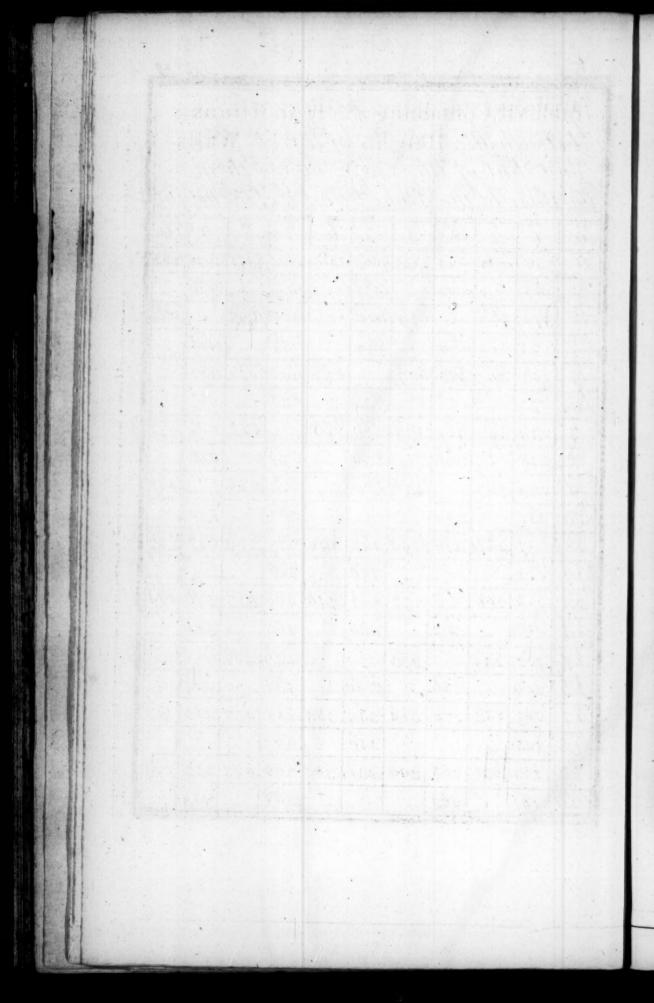
Draw F L perpendicular to the base AG; then if, for conveniency fake, we suppose CF to be one eighth, and the base DG three eighths of the height DC; the area of the rectangle DC, will be \frac{1}{8} a a, that of the triangle LGF, will also be one eighth of aa; and because the distances of the lines drawn through the centers of gravity, of the rectangle DF, and of the triangle F L D, perpendicular to the base DG, from the point fix A, are AD $+\frac{1}{2}$ DL, AL $+\frac{1}{3}$ LG; that is, $x - na + \frac{1}{16}a$; $x + na + \frac{5}{24}a$; and therefore their fum, multiplied by $\frac{1}{8}$ a a, and the product reduced in the ratio of 4 to unity, as has been shewn in the third problem, gives $\frac{1}{16} a a x + \frac{1}{16} n a^3 + \frac{3 \cdot 25}{3 \cdot 3} a^3$, for the momentum of the counterforts, which being added to that of the wall found in the fecond problem, and the fum made equal to that of the earth; after having multiplied by \(\frac{1}{2} \) a, and the second fide reduced under the same denomination, and the root of the first multiplied by the root of the common denominator 81 x 64, we get

	Table V. Containing the Proportions												
	between the Height of Stone Walls and that of the Earth above them												
the	the Base of the Slope being 5 of y height												
0	1	2	3	4	5	6	7	8	9	10			
1	641	1125	1604	2079	2553	3026	3499	3971	4443	4915			
2	391.		885		1365		18 42		2316				
3	305	476		804	965		1285	1445		1762			
4	261		517		763		1005		1246				
5	235	340	442	542		73.9	836	933	1029				
6	217				559		723						
7	205	280	354	427	498	570		711	781	850			
8	194		327		454		579		702				
9	186	247		363	420		532	587		695			
10	180		287				491		591	1			
11	173	225	273	321	368	414	460	506	551	596			
12	171				349		433	1.					
13	168	211	251	292	332	371	411	449	488	527			
14	165		242		318		391		463				
15	162	199		270	1		374	408					
16	160		228		294		359		423				
17	158	190	222	254	285	316	346	376	406	436			
18	156				276		334	•.	٨.				
19	154	183	212	240	268	296	323	351	377	405			
20	152		208				314		366				

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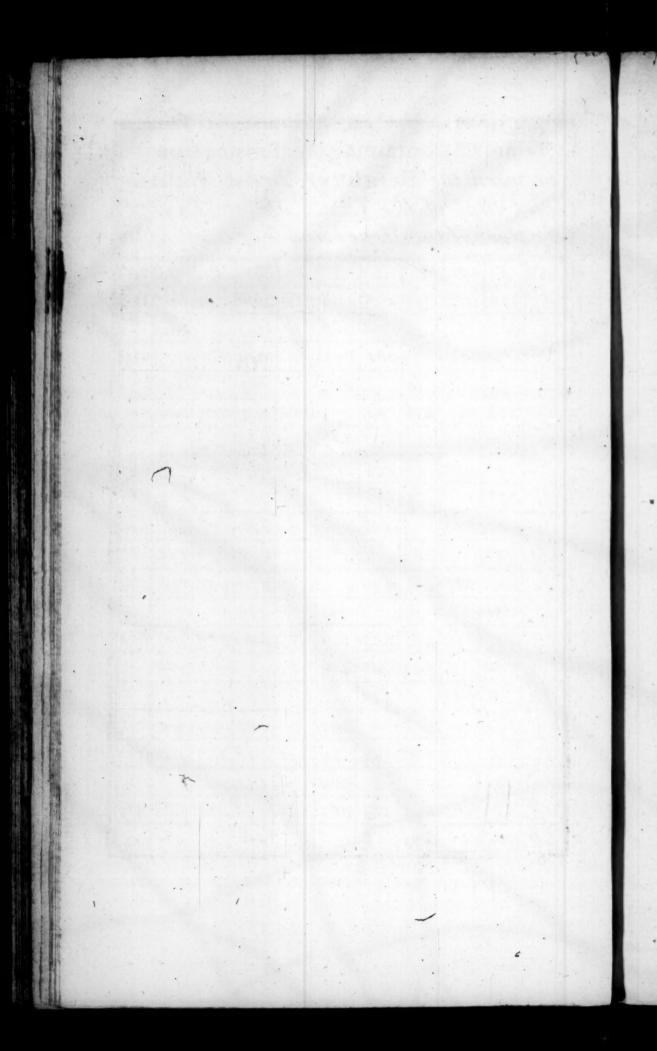
bei	Table VI. Containing the Proportions between the Height of Stone Walls, and that of the Earth above them the Base of the Slope being tof the height												
0	1	2	3	4	5	6	7	8	9	10			
1	672	1157	1636	2//2	2586	3060	3532	4004	4477	4949			
2	422		917		1397		1874		2349				
3	335	506		835	997		1317	1477		1796			
4	291		548		796		1037		1277				
5	264	370	472	57.4		770	868	965	1061				
6	246				589		756		1				
7	233	310	384	458	530	604		742	812	882			
8	223		357		485		610		734	. 7			
9	216	276		393	450		562	617		726			
10	209		317		a ·		523		625				
11	204	254	302	350	400	444	497	536	582	627			
12	200				379		464			-			
13	196	239	281	322	362	403	441	480	519	557			
14	193		272		347		421		494				
15	191	228		300			404	439					
	188		257		324		388		453				
17	186	219	233	284	316	346	377	408	438	466			
18	184				307		364						
19	183	213	241	270	299	327	354	382	409	435			
20	181		237				344		400				



an	TableVII. Containing the Proportions between the Height of Brick Walls and that of the Earth above them the Base of the Slope being 3 of the height												
o o	1	2		4			7	8	a	10			
	748				_		_		1999				
2	468		1020		1557		2089		2620				
3	372	562			1110		1468			2001			
4	323		609		884		1155		1424				
5	293	411	523	637	* .	857	966	1074	1182				
6	273				655		838						
7	259	344	427	509	589	668		826	904	974			
8	248		396		539		678		816				
- 9	239	306	-	436	500		624	686		808			
10	232		352				581		692				
11	227	282	336	390.	442	494	545	596	647	697			
12	222				420		516						
13	218	266	312	357	402	446	490	533	576	619			
14	215		302		386	•	468		549				
15	212	253	1	333			449	487		•			
16	209		286		360		432		504				
17	207	243	279	314	349	383	418	4.52	485	518			
18	205				340		404						
19	203	236	268	300	331	362	392	423	453	843			
20	201		263				382		440	1			

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bet	Table VIII Containing the Proportions between the Height of Brick Walls and that of the Earth above them												
the Base of the Slope being 's of the height													
0	.1	2	3	4	5	6	7	8	9	10			
1	779	1322	1856	2388	2918	3447	3976	4504	5032	5559			
2	499		1052		1589		2/22		2653				
3	402	593		961	1142		1500	1678		2034			
4	354		640		916		1187	•	1456				
5	323	441	556	668		888	997	1106	1214				
6	320				687		870						
7	288	374	459	539	620	700		858	935	1013			
8	277		427		570		710		848				
9	269	336		467	530		656	717		840			
10	262		383				612		724				
11	256	3/2	367	420	473	525	576	627	678	729			
12	251				451		546						
13	247	295	341	387	432	477	521	564	608	651			
14	244		332		416				580				
15	241	282		362			480	518					
16	238		315		390		463		535	1			
17	236	273	309	344	379	414	448	482	516	548			
18	234	1			369		435	. 0					
19	232	265	298	329	361	392	423	453	484	512			
20	230	* **	293				412		470				



 $72x + 72na + 4.5a = a\sqrt{1536}ss - 67.5 + 1728m$, for the equation required, which differs from that found in the third problem, by the term 67.5, which

there is 60.75.

Hence, if n = .2, and ss = .5; these values multiplied by their coefficients, gives 769.62, for the sum of the terms under the radical sign, whose square root is 27.742, from which subtracting the sum 18.9 of the two known terms, and the difference divided by 72, gives x = .1228 a, which is less than that found in the third problem; but not so much as is worth taking notice of: since in a wall of 30 feet high, the difference is only .7 of an inch: consequently either of these counterforts may be used according to the builder's fancy.

Sometimes counterforts may be made with steps, which may be done by making them so as that the base and the area be the same, without changing its

momentum.

Fig. 6. Sometimes the section of walls are made parallelograms without any counterforts, especially when they are low: fuch as ABCD: To find their thickness AD or BC; draw the diagonal AC, and through the middle L, and the point C, the lines L K, C E perpendicular to the base AD produced; and let AD = x, DE = na, and CE = a; then will $a \times express the$ area of the parallelogram DB; and fince the point L is the center of gravity of the parallelogram, A K will be the distance of the line of direction from the point A; but because AL is half of AC, the distance AK, will be $\frac{1}{2}x + \frac{1}{2}na$, half the distance A.E. Therefore the area ax multiplied by the distance AK, gives 1 axx+ 1 aanx, for its momentum, and so equal to 4 ss a3 that of the earth by the first problem; which being divided by \(\frac{1}{2} \) a, and \(\frac{1}{4} \) n n a a, added to both fides: the first will be a perfect square whose root is $18x + 9na = a\sqrt{96}ss + 81nn$, after having reduced the second side under the same denomination, and

and multiplied the root of the first by the root of the

denominator 324, of the fecond.

If the first term 96 s s under the radical sign be increased in the ratio of 4 to 5, we shall have 18 x + $9na = a\sqrt{120} ss + 81 nn$ in walls built with brick.

Hence if n = .2, and ss = .5; we shall get x = .3 to nearly in stone walls, and x = .355 a, in brick walls.

Hence it may be easily known whether these kinds of walls require more masonry, than those in the first figure without counterforts: for we have found in the second problem, when n and ss expressed the same values as here, that x = .2018 a, and therefore the area of that profil, will come out to be .3018 a a; and the area of the parallelogram DB, is .31 a a: therefore the difference .0082 a a, shews that this last figure requires more than the former; tho' not much in low walls.

Before we conclude this fection, we shall add one general problem more, in order to shew that it would have been easy to reduce almost every thing into a few problems, were it not necessary to menage the learners capacity, and to lead him gradually from the most simple and easy truths, to others more complex.

PROBLEM VII.

Let the profil of a stone wall be a parallelogram as DB, and the counterforts a trapezium DCFH, whose outward slope FH being equal to CD that of the wall, to find the thickness of the wall when there is a parapet of earth above it. Fig. 7.

If, for conveniency take, CF be one tenth of the height CE; and the rest the same as before; then will $DH = 2na + \frac{1}{10}a$; which being added to CF, $\frac{1}{10}a$, and the sum multiplied by half the height CE, gives $naa + \frac{1}{10}a$ a for the area of the trapezium, which being multiplied by $AD + \frac{1}{2}DH$, that is $x + \frac{1}{10}a$

 $na + \frac{1}{2} a$, and the product reduced in the ratio of 4 to unity, gives $\frac{1}{4} a a x + \frac{1}{4} n n a^3 + \frac{3}{3} a n a^3 + \frac{1}{3} a a^3$ for its momentum; which being added to $\frac{1}{2} a a x + \frac{1}{2} n a a x$ that of the wall found above, and the fum made equal to $\frac{2}{27} s s \times 3 a b b - a^3$ that of earth, found in the fifth problem; the whole being divided by $\frac{1}{4} a$, and $\frac{1}{16} n n a - \frac{3}{8} a n a a - \frac{1}{8} a a$, added to both fides, the first will be a perfect square, and the second, being reduced under the same denomination, gives $36 x + 27 n a + .9 a = \sqrt{192} s \times 3 b b - a a + 81 n n a a - 48.6 n n a - 2.43 a a$, after having multiplied the first side by 36 the root of the common denominator 1296 of the second.

When the wall is made of brick, there need no more than to increase the coefficient 192, of the first term under the radical sign, in the ratio of 4 to 5, which gives 240 for that coefficient in this case; the

other terms will remain the same as before.

When there is no parapet of earth above the wall, then will b = a; and the first term under the radical fign becomes 384 ssaa. and the rest will remain as before.

When n = .2, and ss = .5; then will $36x + 6.3a = \sqrt{288 bb} - 104.91 aa$, in stone walls: but if $n = \frac{1}{6}$, and ss = .5; then will $36x + 5.4a = \sqrt{288 bb} - 104.91$

98.97 aa.

And if b = a; that is, if there is no parapet of earth above the wall, we shall have x = .202 a, in the first case, and x = .232 a, in the second. But if the height of the wall is to that of the earth above it, as 4 to 3, then will $b = \frac{7}{4}a$; the square of which being substituted into the two equations, gives 882 a a, for the first term under the radical sign, and the square root being extracted, we shall find that x = .6a nearly in the first case, and x = .627 a, in the second.

Hence it is very easy to compare the quantity of masonry, contained in walls, whose profil is a parallelongram

logram as in this figure, and the counterforts a trapezium; and those whose profil is a trapezium, and the counterforts rectangles, as in the second profil: for the area of the profil in the second figure, with that of the counterfort reduced, is found to be .287 a a, when $n = \frac{1}{5}$, and 299 a a, when $n = \frac{1}{6}$.

And the aera of the profil and counterfort, according to the feventh figure, is found to be .277 a a when

 $n = \frac{1}{5}$; and .298 a a, when $n = \frac{1}{5}$.

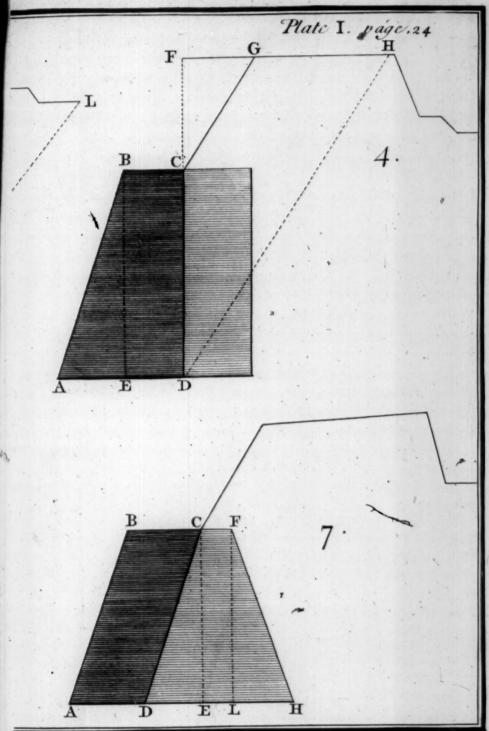
Therefore the profil in the form of a parallelogram, requires less masonry than that whose figure is a trapezium; and the difference is greater when $n = \frac{1}{5}$, than when $n = \frac{1}{6}$; but when n is one seventh or eighth, the trapezium figure has the advantage, as will be

found by computation.

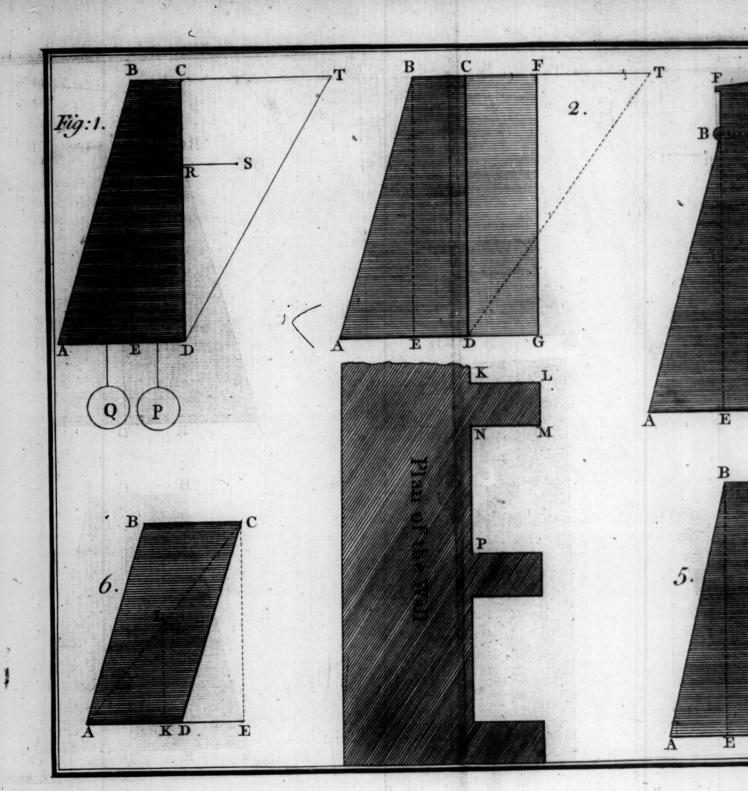
Thus we have shewn how to find the thickness of walls, such as shall resist the pressure of the earth, of all the different profils, that may be used; and it will easily appear, that our method is both more general, and much easier than that given by other authors; the many general rules given here before, and their easy application to practice, are convincing proofs of it; besides no author has attempted before to give tables for ramparts with demi-revetements; though they are much more useful than any other, on account, that the most experienced engineers, scarcely build any others now-a-day, and that for very good reasons; because it saves great expences, besides they are not so easily destroyed by battering pieces, and, when a breach is made, are soon repaired.

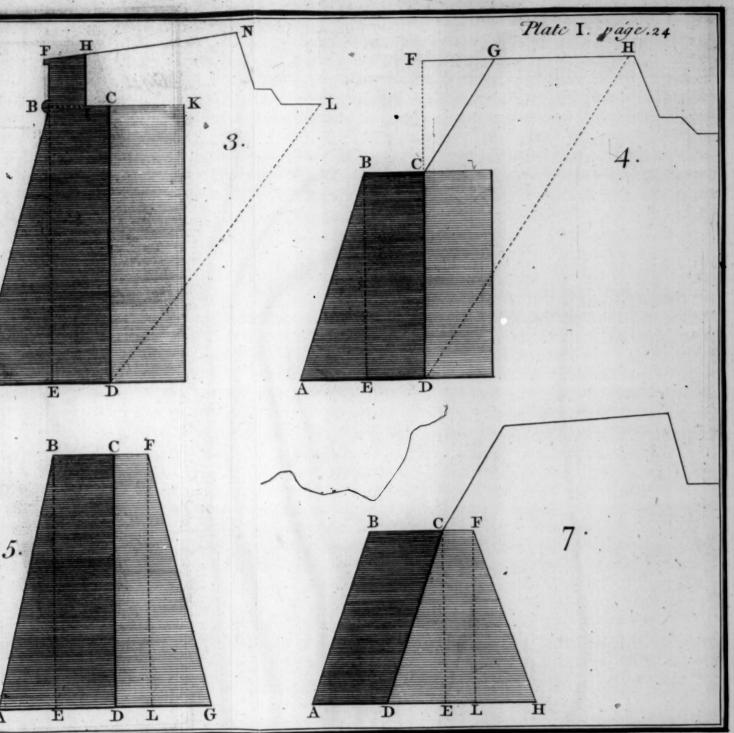
It may perhaps be faid, that we have reduced the counterforts to certain figures which are easily computed, and therefore our solutions are not so general as is pretended: But if the reader be pleased to consider that the length given here agrees very nearly with that given by Mr. Vauban, and the rectaugular form has been shewn to be more advantageous, than that of a trapezium, besides it is generally used here: As to

thosa

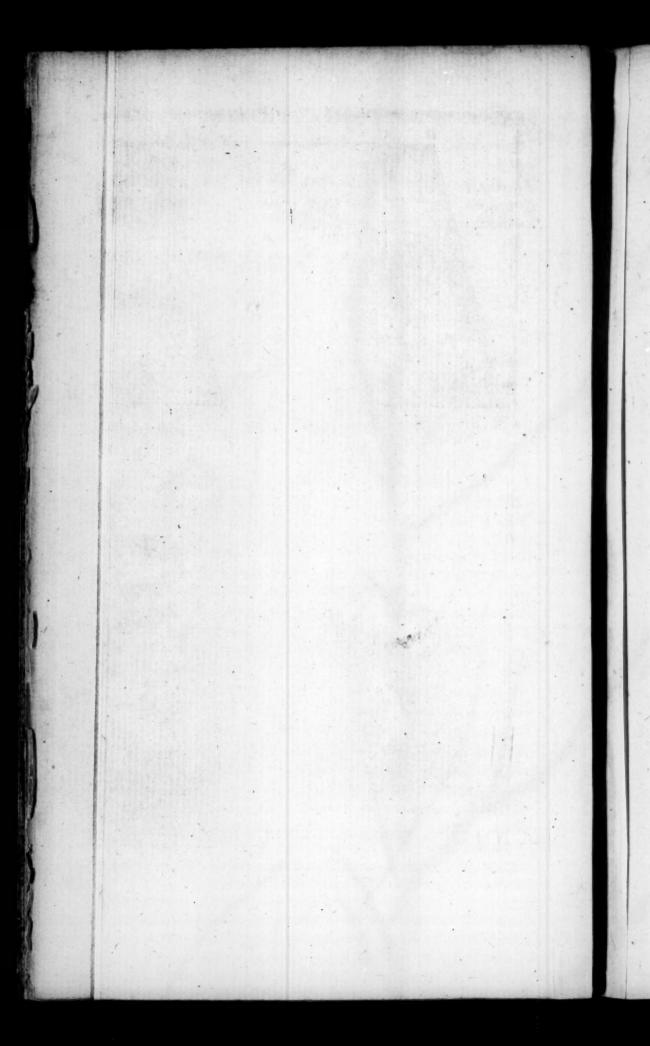


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9. Couse Sculp!



those whose profil is a trapezium, such as in the fifth and fixth figures; regard has been had to such dimensions as are most useful in practice, and such as are of a due proportion in respect to the walls which they are to strengthen.

SECT. II.

The THEORY of ARCHES.

In fortresses it is absolutely necessary to build vaults and arches, such as over gate-ways, under-ground passages, from the body of the place to the ditch, powder-magazines, cazemats, and lodgings for the sick and wounded, and for those which are not on

duty, to rest in with safety.

It is of no little importance, in the building of a fortress, to know exactly, and with certainty, what thickness piers that support arches of various magnitudes, require in different circumstances, so as to make the work durable, and to use no more materials than it requires. The making powder-magazines, fo as to refift the shells thrown upon them in a siege, requires the utmost skill of an engineer, and has not hitherto been rightly determined by any body I know of. The engineers generally follow the dimensions of those constructed by Mr. Vauban, which indeed have so well fucceeded, that it feems to be unnecessary to attempt any other rules to go by; were it not required, in many cases, to make arches of different width, figure, higher and lower; and therefore, it will be proper to lay down general rules, which shall answer all these various circumstances.

It is one of the most difficult problems in mechanics, to find the momentum or force with which different kinds of arches act against the piers that support them; and though many great mathematicians have endear-

youred

Academy of Sciences at Paris, and Mr. Belider in his book called La science des Ingenieurs; yet, if I am not mistaken, neither of them has succeeded; for whoever reads their performances will be more convinced of the difficulties that attend it, than of the truth of their solutions; and it is easily perceived that some of them are mistaken, and have perplexed themselves with tedious algebraic expressions, which when applied to easy practical cases are impossible, which shews that their computations are built upon erroneous principles.

It is true, Mr. Belidor has better succeeded in his principles than many others; yet his applications are not free from objections, as will appear hereafter, and which is the reason that the thickness of the piers he assigns are so much less than they should be.

It feems to be a difficult matter to determine this problem exactly, on account of the suppositions which are necessarily to be made in regard to the cement that is used in the joints, in order to keep the arch-stones

together.

Those who go upon the refined supposition that the joints are quite smooth and polished, without any mortar, are greatly mistaken; for besides that no such thing subsists in practice, their solutions, when applied to practical examples, give nothing but impossibilities, as any one may be convinced who reads them with attention.

In the enusuing work, we shall suppose, with Mr. Belider, that the arch-stones are laid in mortar, and so cemented together as to prevent their sliding upon one another; but not so hard as to compose as it were one solid stone, because this would be a plain contradiction, since it could not act upon the piers in an oblique manner; but the mortar being of such a consistence only, that if the piers were not sufficiently strong, the arch would break in the weakest part, and thereby overturn the piers. This supposition is the most natural

that can be made, and has been found true in practice; for feveral arches have fallen down, for want of fufficient strength in the piers to resist their pressure; besides mortar requires some time to harden, which being once effected, no accidents happen afterwards.

PROBLEM I.

To find the pressure of an arch against the piers that support it. Plate II. Figure I.

Let AEFG be the section of half the arch, ABCD that of the pier which supports it; the point C taken near the foundation, may be considered as fixed, and about which the pier must turn to be overset; MN, one of the arch-stones; O the center where all the joints meet when produced; and lastly, let AS be the

line which terminates the spring of the arch.

From the center of gravity X of the stone M N, draw the vertical X T, and the perpendicular X Q to the joint O M; and from any point a in X T, draw a b perpendicular to X Q and b d to X T: then the weight of the stone M N is to its effect in the direction b X as a X is to b X, and to that in the direction a b, as a X is to a b: as this last effect is destroyed by the friction of the stones together with the mortar, the sirst b X is only to be considered. But the force b X is equivalent to the forces b d, d X, the sirst perpendicular, and the second parallel to the direction C V in which the pier resists, by art 445 of our elem. and as this last is destroyed by the contrary action of the other half arch, the sirst b d is only to be considered.

If from the point fixed C, the line CQ be drawn perpendicular to the direction XQ, and XQ interfects CV in R, then as the angles CRQ, bXd, are equal, the right angled triangles CRQ, bXd,

are fimilar; therefore CR: CQ::bX: bd, or

 $CR \times bd = CQ \times bX$.

Since then the momentum (art. 422) CQXbX of the force b X is equal to the product of the force bd, multiplied by the distance CR, and what has been proved of one arch-stone, is equally true of any other; by the property of the center of gravity (cart. 422) the momentum of half the arch against the pier, is equal to the product of its weight applied to its center of gravity, multiplied by the respective distance CR, from the point C to its direction X R.

If therefore, the point L be the center of gravity of AEFG half the arch, and LI, drawn perpendicular to OM, interfects OD in H and meets CV in I: the product of the fum of all the weights in the direction b d multiplied by the distance C I, will express the total momentum of the pressure of the arch

against the pier,

COR.

Hence if LK be perpendicular to AO, and s denotes the fine of the angle LOK, r its cofine, the radius being unity; and if n expresses the weight of half the arch; the right angled similar triangles LKO, X b d, give 1:r::a X:b X=rn, and 1:s::bX:bd=rsn: this value of bd, being wrote into CR x b d, and C I for CR, gives r s n x x C I for the momentum of the pressure against the pier; and if W expresses the weight of the pier, we have $r s n \times CI = \frac{1}{2} B C \times W$, in a state of rest; by art. 427.

COR. II.

When the arch is femi-circular, then $r = s = \sqrt{\frac{1}{2}}$, and when it is elliptical or an arc of a circle, the height OE is feldom less than the two thirds of half the width AS; and in this case s is to r as 2 to 3, and the radius $\sqrt{4+9} = \sqrt{13}$; whence $rs = \frac{6}{13} =$

 $\frac{1}{2} - \frac{1}{26}$; which differs so little from that in a semicircle; by supposing $r = \frac{1}{2}$, the difference will scarcely be sensible inpractice: and if n expresses half the area A E F G; the equation in the last corollary, becomes $2n \times CI = BC \times W$.

COR. III.

If the friction of the stones be considered, let q express the weight which would just move a stone lying upon another placed horizontally: then because that weight or force is to its effect in any other direction OM, as the radius is to the fine s of the angle LOK (art. 499,) that is, s q will express that effect: and the radius is to the cofine r as the effect in the direction O M is to rsq the effect in the horizontal direction b d, which being subtracted from the force r s n in that direction found above, gives r s $\times n - q$ XCI= BCXW: or because it has been found by experiment, that a force equal to one third of the weight, will move a body in a horizontal direction upon a smooth plane: the force q will therefore at least be equal to one third of the weight n: hence $\frac{2}{3}$ r s n × C I = $\frac{1}{2}$ B C × W, or when rs = $\frac{1}{2}$, and n expresses one third of the area AEFG, we get 2 nx $CI = BC \times W$, as before.

REMARK I.

As the surfaces of the arch-stones are generally very rough, and besides the mortar renders them less liable to slide upon one another, than they would do without it; the momentum we have here given, is more than what arises barely from the weights of the arch stones; and even more than when the weight n is diminished by one third, on account of the friction as in the last corollary; but as arches under ground support a weight of earth, besides its own, and those above ground, ought

ought to refift the force of shells, we shall not diminish that momentum hereafter in our computation; leaving to the engineers to make it less whenever they shall think it necessary; which they may do, by supposing n to express any part of the area AEFG; in the following equations.

REMARK II.

As the angle AOL increases, so the perpendicular Q C or the momentum of the arch increases, till that angle becomes a right one; then CQ becomes equal to the line CV, terminated by the horizontal line, passing through the middle of the upper joint EF; and therefore CV is the greatest distance CQ of all the CQ's; and when XQ paffes through the point fix C; then C Q becomes nothing; and when the direction X Q passes between the points B, C, it becomes negative, and the greatest when equal to DG + 1 A G, and the part of the arch from the point where C Q = 0 to the spring A D, instead of acting against the pier, add strength to it, but as the above property of the center of gravity is general, whether a part is negative or not; we have no occasion to confider the negative part separately.

PROBLEM II.

To find the thickness of the piers BC, when the arch is terminated by two concentric circles described from center O placed in the line AS, which passes through the spring of the arch.

Let the radius O A of the interior circle be a, that O G of the exterior b, the height of the pier AB=c, its thickness sought BC=z, and the perpendicular L K = m; then as the right angled triangles O H L, H D I, are isosceles, we have O H = 2m, D H or D I = a + z - 2 m, and C I = c - a - z + 2m, or if g = c + 2m

—a, CI = g - z; and as W = cz; these values wrote into $2 n \times CI = BC \times W$. found in Cor. 2, give 2ng - 2nz = czz or czz + 2nz = 2ng, whose square

root is $c z + n = \sqrt{2cng + nn}$.

By means of this equation the thickness of the pier may be found; but before it can be applied, the values of n and m must be determined. Let therefore unity be to r as the diameter to its circumference; then $\frac{1}{4}ra^2$, $\frac{1}{4}rb^2$, will express the areas of the quadrants by art. 175; and 4n = rbb - raa. The semi-spheres described by these quadrants about the axis O A, are (art. 216) $\frac{2}{3}ra^3$, $\frac{2}{3}rb^3$ and their difference will be the solid described by the area of the arch about the same axis, which solid is also equal to the product of the generating plane n and the circumference 2rm described by the center of gravity L (art. 425). Hence $2rnm=\frac{2}{3}rb^3-\frac{2}{3}ra^3$, or $3nm=b^3-a^3$, when reduced; and this equation divided by 4n=rbb-raa, gives $\frac{1}{4}rm=a+\frac{b}{a+b}$.

EXAMPLE.

Let a=12, b=c=15; then because r=3.14159. (art. 252) we get $n=\frac{1}{4}r \times bb-aa=63.6171$ or $\frac{1}{4}n=31.808\frac{1}{2}$, $a+\frac{bb}{a+b}=20\frac{1}{3}$, and hence m=8.629, g=c+2m-a=20.258; which gives 2cg+n=639.548, this multiplied by $31.808\frac{1}{2}$, gives 20343. 062558 for the sum of the terms under the radical sign, whose square root is 142.629, from which subtracting the known term 31.808 and dividing the difference by the coefficient (c) 15 gives z=7.388, or B C equal to 7 feet and 4 inches.

If we take 21.2056, one third of the value *n*, on account of friction, then 2 cg+n=628.9456, which multiplied by 21.2056, gives 13337.168815 for the fum of the terms under the radical tign, whose square

root is 115.866; from which subtracting the known term 21.2056, and dividing the difference by the coefficient 15 gives z = 6.285, or B C equal to 6 feet 3 inches.

PROBLEM III.

To find the thickness BC of the piers, when the outside GF is a right line perpendicular to the radius OM which bisects the quadrant OAE. Fig. 2.

It is evident that the triangles OLD, HDI, are the fame here as in the first figure, and therefore this problem differs from the former only in the values of n and m: whence if OM = b, and the rest as before; then because the right angled triangle GOF is isosceles, we have GF = 2b, and so b expresses the area of that triangle, and as $\frac{1}{4}r$ a a expresses the quadrant OAE, we have $n = bb - \frac{1}{4}r$ a a.

Because OF = $b\sqrt{2}$, the cone described by the triangle OFG, about the axis OF, will be expressed by $\frac{2}{3}rb^3\sqrt{2}$, and the semi-sphere being $\frac{2}{3}ra^3$, by the last problem; and since unity is to 2r, as the radius K L or OK (m) is to the circumference 2rm described by the center of gravity L in the rotation, we have $3nm = b^3\sqrt{2} - a^3$, by what has been said before, after multiplying by 3 and dividing by 2r: confequently g = c + 2m - a, and $cz + n = \sqrt{2cgn + nn}$ as before.

EXAMPLE.

Let a = 12.5, b = 15.5, c = 15; then will n = 117.5387, m = 9.3988, g = 21.2976, and if we take 58.7694 half the value of n, we get 2 c g + n = 697.6974, which multiplied by 58.7694 gives 41003.257579, for the fum of the terms under the radical

radical fign, whose square root is 202.492, from which taking the known term 58.769 and dividing the difference by the coefficient 15 gives z = 9.58, or B C

equal to o feet 7 inches.

But if we take 39.1796, one third only, on account of the friction, we then get 2cg + n = 678.1076; this multiplied by 39.1796, gives 26567.984525 for the sum of the terms under the radical sign, whose square root is 162.996, from which taking the known term 39.179 and dividing the difference by the coefficient 15 gives z = 8.254, or B C equal to 8 feet 3 inches.

REMARK.

All arches require a certain thickness at the hanches M to support their own weight, and in powder magazines, to refift the shock of shells besides, but how to determine it exactly is not eafily done: It is true, that Mr. Vauban, makes it 3 feet in an arch of 25 feet wide, and as his powder magazines have been found strong enough by all accounts; there is no reason to doubt, but that this thickness is sufficient for arches of that width: And if we confider that the force, which a timber fcantling supports, is as the square of its height divided by the leaver of the force applied; as will be shewn in the next section prob. I; Then as the height of the scantling, is represented here by the thickness of the arch and the leaver by the radius of the arch: the radius 15.5 feet is to any other radius as the square 9 of the thickness 3, is to the square of the thickness sought. Hence this rule; multiply the radius of any arch by 9, and divide the product by 12.5; then the square root of the quotient will be the thickness of that arch.

PROBLEM IV.

To find the thickness B C of the piers when the infide is a right line parallel to the outside.

The fame thing being supposed as in the last, we shall have $n = b \ b - a \ a$, $3 \ n \ m = \overline{b^3 - a^3} \times \sqrt{2}$ or $\frac{3 \ m}{\sqrt{2}} = a + \frac{b \ b}{a + b}$, $g = c + 2 \ m - a$, and $c \ z + n = \sqrt{2 \ c \ g \ n + n \ n}$.

EXAMPLE.

Let a = 12.5, b = 15. c = 15; then, n = 84, a + b = 15. c = 15; then, n = 84, a + b = 15. c = 15; then, n = 84, a + b = 15. c = 15; then, n = 84, a + b = 15. c = 15; then, n = 84, a + b = 15. c = 15; then, n = 84, a + b = 15. a + b = 15.

PROBLEM V.

To find the thickness B C of the piers when the arch is terminated by two circular arcs, described from the same center O, below the line A S which passes through the spring of the arch. Fig. 3.

Let the chord A E be drawn; the radius A O produced fo as to meet the arc G F in R, and the line O D

O D parallel to P A, meeting C I in D, and interfecting the direction L I in H; then if O A = a, O M = b, A P = p, P E = d, A E = b, and the arc A E = v.

This being supposed, we shall have $\frac{1}{2}av$ for the area of the sector O A E, and as the sectors O A E, O R F, are similar, they are as the squares of the radii, therefore $aa:bb::\frac{1}{2}av:\frac{bbv}{2a}=$ to the sector

ORE; and 2 an = v x bb - a q.

Now because the solids described by these sectors in the rotation of the figure about a line passing through the center O perpendicular to the radius O M, are the two thirds of the cylinders of the same bases, and whose altitudes are the chords of these arcs, by art. 217. of our Elem. Math. the bases being ra a, r b b, and the altitudes, b, $\frac{b}{a}$, these solids are $\frac{2}{3}r$ a a b, $\frac{2}{3}r$ b b, and

if OL = m, then will $3 amn = b \times b^3 - a^3$. The right angled triangles OLH, HDI, are fimilar to the triangle APE, and therefore PE(d): AE

(b):: OL (m): OH = $\frac{bm}{d}$, and foDH = p + a

 $-\frac{bm}{d}$; we have likewise A P (p): PE (d):: DH:

D $I = d + \frac{dz}{p} - \frac{bm}{p}$; now because O P = a - d, by subtracting the sum of D I and O P = a - d, from the height of the pier c; we shall have C $I = c - a + \frac{bm}{p} - \frac{dz}{p}$; or if $g = c - a + \frac{bm}{p}$, it will be C $I = g - \frac{dz}{p}$, and consequently, $czz = 2ng - \frac{2ndz}{p}$ by cor. after prob. I. and if dn = pq; the square root

of this equation will be $cz + q = \sqrt{2} cng + qq$. Hence, if the height P E of the arch be the two thirds of A P; that is if $d = \frac{2}{3}p$; the right angled triangle A P E, gives $b = \frac{2}{3} p \sqrt{13}$, and the right angled triangle A P O, gives 12 a = 13 p, because PO = a - d, $q = \frac{d}{p}n$, we get $PO = \frac{5}{13} a$, $q = \frac{2}{3} n$, and $g = c + \frac{1}{3} m \sqrt{13} - a$. But A O (a) is to P O $(\frac{5}{13} a)$ as the radius 100000 is to 38461 the cosine of the angle A O P, and therefore this angle is 67 degrees and 23 minutes nearly or $67 \frac{2}{60}$ degrees. Now because ra expresses half the circumference of the radius a, we have 180 degrees is to $67 \frac{2}{60}$ degrees as ra is to $v = \frac{4043}{10800} ra$.

EXAMPLE.

Let A P = p = 12, c = 15, then will a = 13, b = 16; hence b = 14.422, v = 15.2887, n = 51.1583, m = 13.727, q = 17.0527, g = 18.4975; and 2 c n g = 14.194.5095, q q = 290.9753: therefore 14485.4848 is the sum of the terms under the radical sign, whose square root is 120.355, from which subtracting the known term 17.053, and dividing the difference by the coefficient 15, gives z = 6.886 or B C equal to 6 feet 10 inches, which is less than z = 7.388 found in the second problem.

PROBLEM VI.

To find the thickness BC of the piers when the outfide GF is a right line parallel to the chord AE, and the rest being the same as before. Fig. 4.

It is evident that this problem differs from the former, in the values of m and n only. Whence because of the right angled similar triangles APE, OMF, we have AP (p): PE (d):: OM (b): MF = $\frac{b d}{p}$;

and as MR is equal to MF, we have $\frac{bbd}{p}$ for the area of the triangle ORF, and fince $\frac{1}{2}$ a v expresses the area of the sector OAE by the last problem, we

have 2pn = 2dbb - apv.

Now because the solid described by the triangle OR·F about an axis passing through the center O parallel to the chord A E, is the two thirds of the cylinder of the same base and altitude; the base being rbb, and the altitude R F, $\frac{2bd}{p}$, this solid will be $\frac{4r}{3p}db^3$; and as the solid described by the sector OAE, in that rotation, is $\frac{2}{3}$ raab; we get 3 mnp = 2 db 3 a abp; after having multiplied both sides by 3 p and divided by 2 r.

Therefore $g = c - a + \frac{bm}{p}$ and $cz + q = \sqrt{2cng + qq}$, by the last: supposing dn = pq. If the center O be supposed to coincide with the point P; then a, p, and d, are equal, and the equations in the two last problems, will then become the very same as those in problems the second and third, with this re-

ferve, that O L is here called m, and L K in the first and second figure.

If P. E be again the two thirds of AP; we shall find the same values as in the last; that is, $d = \frac{2}{3}p$, $q = \frac{2}{3}n$, 12 a = 13p, $b = \frac{1}{3}p\sqrt{13}$, $g = c + \frac{1}{3}m\sqrt{13} - a$, and $v = \frac{4043}{10000}ra$.

EXAMPLE.

Let p = 12, c = 15; then a = 13, b = 16, v = 15.288, n = 71.289, m = 14.139; and if we take

take half the value of n, we get q = 23.763, 2cng = 20312.0183, qq = 564.6802, and 20876.6985, will be the fum of the terms under the radical fign; whose square root is 144.487, from which subtracting the known term 23.763, and dividing the difference by the coefficient 15, gives z = 8.04, which is less than z = 8.254, found in the third problem.

N. B. We have neglected the small space AGR, in the two last sigures, as being but inconsiderable, and would have rendered the operations very tedious; besides in practice a geometrical exactness is impossible and not necessary; especially when the departing from it renders the operations more easy and simple, as it happens here in this case.

PROBLEM VII.

To find the thickness B C of the piers, when the arch is terminated by two circular arcs described from the center O, placed in the line AS, which passes through the spring of the arch. Fig. 5.

It is evident that the values of m and n are here the fame as in the fifth problem, fince we have the fame fectors and triangles here as in the third figure; there-

fore
$$2na = vv \times \overline{bb-aa}$$
, and $\frac{3vm}{2b} = a + \frac{bb}{a+b}$.

Now because of the similar triangles PEA, OLH, we have PE(d): AE(b):: OL(m): OH = $\frac{bm}{d}$, and so $a+z-\frac{bm}{d}$ = DH; and the similar trangles APE, DHI, give AP(p): PE(d):: DH: DI = $\frac{da}{p}+\frac{dz}{p}-\frac{bm}{p}$; whence CI = $c-\frac{da}{p}-\frac{dz}{p}+\frac{dz}{p}$

 $\frac{b m}{p}$, or if $g = c - \frac{d a}{p} + \frac{b m}{p}$; then will C I=g-

 $\frac{dz}{p}$; consequently, $czz = 2 ng - \frac{2 dnz}{p}$; by corol. after the first problem; and if dn = pq; the square root of this equation will be $cz+q = \sqrt{2cng+qq}$.

If O P is one fourth of the radius O A; that is, if the radius is the two thirds of the span of the arch, then will A P = $p = \frac{3}{4}a$; and the right angled triangle O P E, gives P E = $d = \frac{1}{4}a\sqrt{15}$, and the right angled triangle A P E, gives AE = $b = \frac{1}{2}a\sqrt{6}$. But O E (a) is to P O ($\frac{1}{4}a$) as the radius 100000 is to the cosine 25000 of the A O E, which is found to be 75 degrees and 32 minutes, or 75.5 $\frac{1}{3}$ degrees.

And fince unity is to 3.14159, as the radius a is to the femi-circumference 3.14159 a; and 180 degrees is to $75.5\frac{1}{3}$ as the femi-circumference 3.14159 a, is to the arc v = 1.32 a nearly.

EXAMPLE.

Let A P = 12, c = 15; then will a = 16, b = 19; hence n = 69.3, m = 16.2645, g = 20.8985; and if we take half the value of n, we get q = 44.733, 2cng = 21723.9907, qq = 2001.0413, and the sum of the terms under the radical sign will be, 23725.032; whose square root is 154.028; from which subtracting the known term 44.733, and dividing the difference by the coefficient 15, gives z = 7.2, which is less than z = 7.388, found after prob. H.

PROBLEM VIII.

To find the thickness BC of the piers, when the outside is a right line parallel to the chord AE, of the inside arc. Fig. 6.

By the similarity of the triangles OMG, APE, we have PE(d): AP(p):: OM(b): GM = $\frac{bp}{d}$; and since GM and MR are equal, we get $\frac{bbp}{d}$ for the area of the triangle OGR, and as the area of the sector OAE is $\frac{1}{2}av$, we have 2nd = 2bbp - adv: But the solid described by the triangle OGR, about an axis passing through the center O parallel to AE, is $\frac{4rp}{3d}b^3$; and that of the sector OAE described in that rotation $\frac{2}{3}raab$; therefore $3dmn = 2pb^3 - aadb$, by what has been said before. And because there are the same triangles here as in the last figure; we have $g = c - \frac{da}{p} + \frac{bm}{p}$, dn = pq, and $cz + q = \sqrt{2cng} + qq$ as before.

If we suppose again that O P is the three fourth of the radius O A; then will the values of p, d, b be the same as before.

EXAMPLE.

Let as in the last be $p = \frac{3}{4}a$, a = 16, b = 19, e = 15; then will $d = \frac{1}{4}a\sqrt{15}$, $b = \frac{1}{2}a\sqrt{6}$, and n = 110.74, v = 1.32a, m = 16.895, g = 21.933, and if we take half the value of n, we get q = 71.796, q = 5154.6656, 2ncg = 36432.9063; therefore the sum of the terms under the radical sign is 4.587.5719; whose square root is 203.93; from which

which subtracting the known term 71.796 and dividing the difference by the coefficient 15 gives, z = 8.8.

N. B. We have neglected the space ERF, in the two last sigures, which could not be considered with-out rendering the operations very tedious and perplexed, and as in practice a scrupulous nicety becomes more troublesome than useful, we aim more at simplicity than a too great mathematical strictness wherever practice is concerned.

LEMMA I.

The diameter O L, which bisects the chord A E, joining the extremities of the two semi-axes A O, and O E, of an ellipsis, bisects the area of the quadrant A L E O. Plate III. Fig. 7.

For the diameter O L bisects all its ordinates which are parallel to that chord, as well as all the lines drawn in the triangle A O E parallel to the base A E; consequently, the diameter L O bisects the area A L E O of the quadrant.

COR. I.

Hence, because the tangent L H, is parallel to the ordinate A E of the diameter O L, by the nature of the ellipsis, and this diameter bisects A E in m, and since A O E is a right angle; A m, m O, m E, are equal; therefore the triangle O m A, is isosceles, and being similar to the triangle O L H, this triangle is likewise isosceles; consequently, O K = K H, and O L = L H.

COR II.

Hence the triangles AOE, OLK, are similar; for the triangles OKL, HKL, having all their sides equal, are equal in all respects: and since the triangle HKL is similar to the triangle AOE, its equal OKL will be so too.

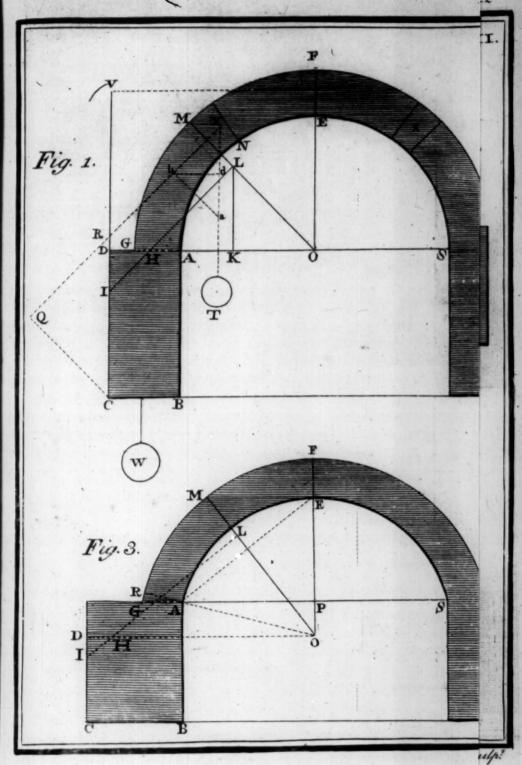
COR. III.

Because OK : OA : OA : OH, or 2OK, by the last corollary; whence $OA = OK\sqrt{2}$; and by the similarity of the triangles AOE, OKL; we have OA : AE : OK : OL, and since $OA = OK\sqrt{2}$; we have $AE = OL\sqrt{2}$ by equality of ratio's.

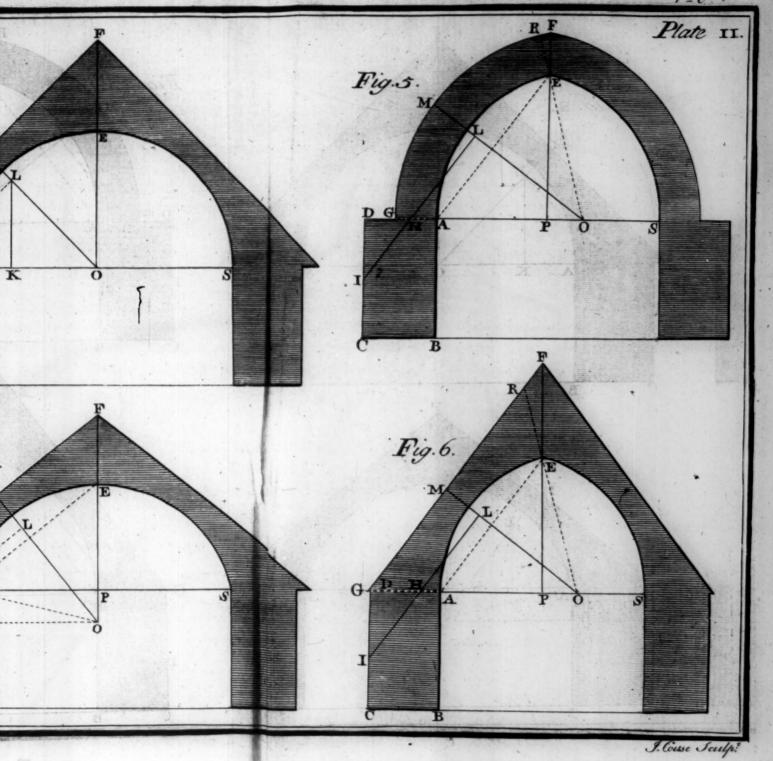
PROBLEM IX.

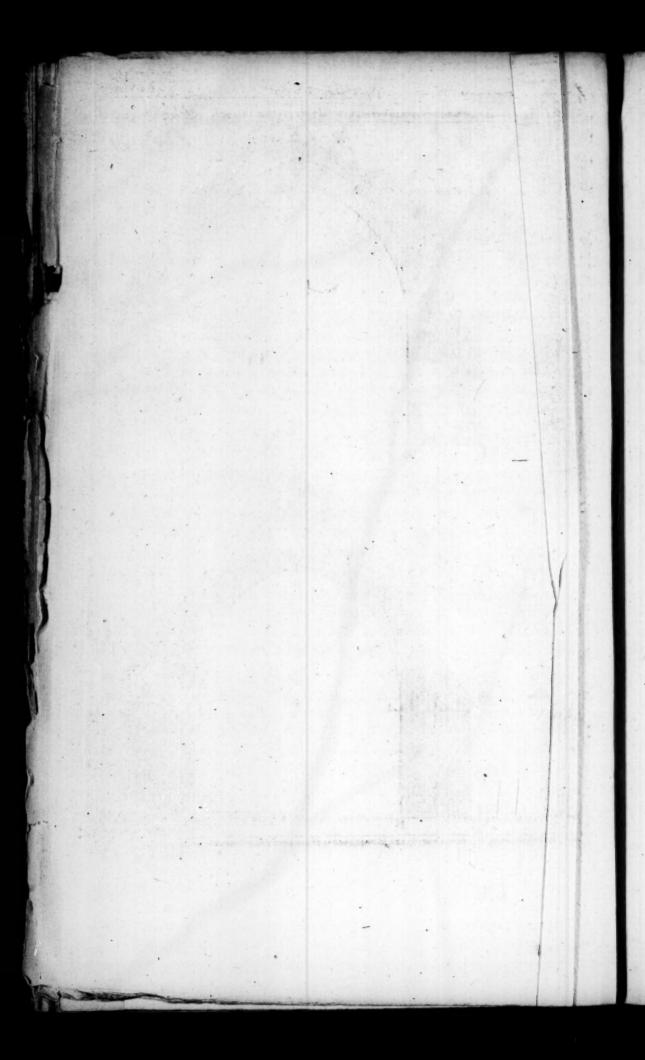
To find the thickness BC of the piers, when GF, AE, are two similar elliptical quadrants, described from the same center O, and the joints are perpendicular to the tangent in that point. Fig. 8.

If O A = a, O G = b, O E = d, and the rest as before; then will O F = $\frac{b d}{a}$, by supposition, whence since the circular quadrant described with the radius O G, b, will be $\frac{1}{4}rbb$, and is to the elliptical quadrant O G F, as O G (b) to O F ($\frac{b d}{a}$) and therefore this elliptic quadrant will be $\frac{rbbd}{a}$; and the quadrant OAE, will be $\frac{1}{4}rad$ by the same reason; therefore $4an = rd \times \overline{bbd} - aa$, after having multiplied by 4a.



B





Now because raa, rbb, express the areas of circles described by the radii O A, O G, in the rotation of the figure about the axis O F, and since the solids described by the elliptical quadrants in this rotation are the two thirds of the cylinders of the same base and altitudes, these solids will be $\frac{2}{3}$ raad, $\frac{2r}{3}db^3$, and their difference equal to 2rm by art. 425. supposing OK = m; which gives $3amn = d \times b^3 - a^3$, after having multiplied by 3a. The first side of this equality being divided by 4an, and the second by its equal, gives $\frac{3}{4}$ $rm = a + \frac{bb}{a+b}$.

If we imagine a quadrant of an ellipsis to be described through the center of gravity L, similar to the former; then the direction L H, will be a tangent to the ellipsis, and therefore perpendicular to the joint passing through that point; and OK = KH, by cor. I, or OH = 2m; hence DH = a + z - 2m; and by the similarity of the triangles AOE, HDI, we have $AO(a):OE(d)::DH:DI = d + \frac{dz}{a}$. $\frac{2md}{a}$, and so $CI = c - d + \frac{2md}{a} - \frac{dz}{a}$; or if $g = c - d + \frac{2dm}{a}$; we have $cz = 2ng - \frac{2ndz}{a}$, by cor. after prob. I. and if aq = nd, the square root of this equation is $cz + q = \sqrt{2cng + qq}$.

EXAMPLE.

Let a = 12, b = c = 15, d = 9; then as r = 3.142 nearly, we get n = 47.72, m = 8.629, g = 18.943, and taking the two thirds of the area 47.72 for the value of n, we shall have q = 23.86 and 18648.4988 for the sum of the terms under the radical sign, whose square root is 136.559, from which subtracting

subtracting the known term 23.86, and dividing the difference by 15, we shall have z = 7.513, or B C equal to 7 feet 6 inches.

PROBLEM X.

To find the thickness BC of the piers, when the outside is a right line GF, parallel to the chord A E which subtends the elliptical quadrant. Fig. 9.

If AO = a, OE = d, OM = b, Om or Am = b, and the rest as before; then by the parallel lines A E, GF; we have Om(b): OE(d)::OM(b):OF= $\frac{b d}{b}$; and O m (b): O A (a):: O M (b): O G = $\frac{a b}{b}$;

whence $\frac{abbd}{abh}$ will express the area of the triangle

GOF, and fince + rad expresses the area of the elliptical quadrant, we have 4bbn = adx 2bb - rbb

after having multiplied by 4 bb.

Now because raa, $\frac{raabb}{bb}$, express the circles dest cribed by the radii, OA, OG, in the rotation of the figure about the axis O F; we have $\frac{2}{3}$ raad, $\frac{raadb^3}{2b^4}$ for the folids described by the quadrant OAE, and the triangle GOF, in that rotation; therefore their difference is equal to 2 r m n by what has been faid before which gives $6 mnb^3 = a a d \times b^3 - 2 b^3$.

As the rest of the figure is the same as before, we have $g = c - d + \frac{2md}{a}$, aq = nd, and cz + q = $\sqrt{2}$ cng +qq, as above.

EXAMPLE.

Let a = 12, d = 9, c = 15; then will b = 7.5. and the diameter $O_n = A E \sqrt{2}$ by cor. 3. will be 10.6, and if we allow 3 feet for the thickness Mn of the arch: we have b = 13.6, whence n = 92.72, m = 9,23, g = 19.845; and if we take 61.812 the two thirds of the area 92.72 for the value of n, we get q = 46.36, and 38949.0238 for the fum of the terms under the radical fign, whose square root is 197,355, from which subtracting the known term 46.36, and dividing the difference by 15, gives z = 10.066, nearly; which is 5 inches more than when the infide is circular, this arises from the difference between the weights of the arches; for we found 112 feet in problem 3, and here only 92.72, fo that either of these arches may be used as occasion shall require.

But if c = 9, and the rest as before; then will z = 9.57, which is very little less than what has been

found in the third problem.

When both sides of the arch are terminated by ellipsis, its piers require less masonry, than when it is terminated by circles; for we found in the second problem 7 feet 4 inches, and in the ninth 7 feet 6 inches, and therefore the difference is 2 inches: notwithstanding Mr. Belidor sound the contrary, and from thence concludes that the elliptic arch has a greater pressure than the circular one: this would be true if the weights of the arches were equal; but we have found the area in the circular one to be 63.62 feet, and 47.72 feet in the ellipsis; and therefore the weight of the circular arch is to the weight of the elliptic arch, as 133 is to 100 nearly. So that the weight of the first is about one third more than in the second.

PROBLEM XI.

To find the thickness BC of the piers when there are counterforts VD; the infide of the arch being circular and the outside a right line. Fig.

Let CV = b, be the length of the counterforts, which have the same height as the piers, and the interval from the one to the other, is to their thickness as two to one.

It is plain that the point C is no more that about which the piers must turn in order to be overset, but it is the point V or extremity of the counterforts: fo that the distance V I of the direction L I, must here be found on the line V R.

If we retain the fame values as before, we get $n = bb - \frac{1}{4}raa$, $3nm = b^3\sqrt{2} - a^3$ and OH = 2m, by the third problem: whence RH = a + b + z -2m, and VI = c - a - b + 2m - z, or if g =c-a-b+2m; then will V1=g-z; therefore 2 ng - 2 nz will be double the momentum of the arch.

And fince cz expresses the area of the pier CA, and $b + \frac{1}{2}z$, the distance of its center of gravity from the line R V, we have cbz + 1 t z z for its momentum; and the area cb of the counterforts multiplied by ½ b, gives ½ c b b for its momentum, which being reduced in the ratio of 3 to unity, gives to bb; therefore twice the sum of these last momentums, must be equal to that above, by cor. after prob. 1, that is $czz + 2cbz + \frac{1}{3}cbb =$ 2 ng - 2 nz; and if q = n + cb; the square root of this equation will be $cz+q=\sqrt{2cng}$ - + ccbb+99.

EXAMPLE.

Let a=12, b=15, c=9, b=4; then will n=112, m=9.072, g=11.144, and q=148; hence 43938.304 will be the sum of the terms under the radical sign, whose square root is 209.614; from which subtracting the known term 148, and dividing the difference by 9, gives z=6.846 feet nearly, or BC equal to 6 feet 10 inches, which is 14 inches only less, than what Mr. Vauban has given to his piers, the coun-

terforts being the same.

If we suppose c = 15, and b = 5; the rest being the same as before, we shall have n = 112, m = 9.072 as before, and g = 16.144, q = 187; whence the sum of the terms under the radical sign is 87337.84, whose square root is 295.529, from which subtracting the known term 187, and dividing the difference by 15, gives z = 7.235 nearly, or B C equal to 7 seet 3 inches nearly, whereas Mr. Belidor sinds but 3 feet one inch for the same thickness; which methinks might have given him reason to suspect his theory, as differing so widely from Mr. Vauban's practice, although the latter did not deduce his rules from any theory, yet his great practice made him arrive generally pretty near the truth.

If we suppose the height of the piers c to be 9 feet, and the length b, 3 feet only, we shall find z = 7.746 or B C equal to 7 feet 9 inches nearly, which differs from the thickness given by Mr. Vauban, by 3 inches only; so that, according to this theory, he made the length of his counterforts one foot more than is re-

quired.

Having considered that most practitioners are unacquainted with algebra, and being willing to render this book useful to every person employed in these works, we imagined that a table containing the dimensions of the piers of different width of arches would be acceptable to many of my readers, for which reason we have inserted the following one.

A

A TABLE containing the thickness of the piers of Powder Magazines.

36	8.754	9.164	9.494	9.822	5 10.123	10.402	199 01	10.894	11.125	11.33	11.528	11.710
34	8.465	8.821	9.171	9.479	9.765	10.027	10.270	10.493	10.712	10.868	080.1	11.218
	8.165	8.510	8.834	9.125	9.392	9.638	9.801	10.073	10.268	10.443	10.612	10.772
30	7.855	8.180	8.184	8.757	90006	9.230	9.456	9.636	9.816	9 982	10.136	10.279
26 28	3.9697.545	.4837.841	7.741 8.120	.9748.375	1.1858.604	3.3718.814	.5539.006	7149.185	.8699.348	998 9.499	1259.627	242 9.769
24	2 6.844	7.1067	57.3437	87.5547	27.7478	5 7.922 8	8 8.079 3	5 8.223 8	8.349 8	8.4798	8.590	8.694
20 22	0.082 6.47	97 6.74	86 6.93	57 7.11	09 7.292	39 7.44	53 7.58	.r807.71	00 1	73 7.948	57 8.038	37 8.129
18 2	6666.0	.855 6.2	0.021 6.4	0.168 6.6	6.298 6.809	.418 6.939	6.521 7.05	6.616 7.1	.703/7.278	.7837.3	8597.4	921/7.5
91	5.224 5	5.3865	5.53310	5,6490	5.763	9.861	5.949	6.031	6.1066	6.1676	6.2276	6.282 6
I 4	94.750	7 4 88 5	200.5	95.105	2 5.179	3 5.267	5 348	5,411	694.5	5.522	5.503	5.614
12	64.23	8 4.347	84.440	:	04.592	4.	94.711	64.761	94.806	8 4.847	2 4.884	14.917
10	3.68	3.76	3.83	3.899	3.950	3.990	1.0394	1.07	601.t	1.13	4.17	4.257
	6	10	=	12	13	14	15	91	17	f.b	61	20

The first line 10, 12, 14, &c. expresses the width of the arches in seet; the rest of the lines, the thicknesses of the piers in seet and decimals, answering to their heights marked in seet in the first column 9, 10, 11, 12, &c. respectively from 9 to 20 feet.

It may be observed that the length of the counterforts, have here been made one sixth part of the opening of the arch, or 3 b is always equal to the radius a: which proportion we found to be most agreeable in regard to the thickness of the piers; for by making the counterforts longer, the piers of small arches would become so thin, and the materials would thereby not join so well, which ought to be avoided.

Those who are not versed in Algebra, may depend on the dimensions here given, and that the arches will be good and lasting, provided the work is well executed, and the materials good; it is however adviseable to leave the centers standing at least for six months, in order to give time to the masonry to settle and harden; which being done, the work will not fail afterwards.

PROBLEM XII.

To find the thickness of the piers, having counterforts when the inside is an ellipsis. Fig. 10.

Because we have $6 m n b^3 = a a d \times \overline{b^3 - 2b^3}$ and $4 bb n = a d \times \overline{2bb - rbb}$ by problem X; and R H = a + l + z - 2 m, by the last problem, supposing C V = l; and by the similarity of the triangles OAE, RHI, we have AO(a):OE(d)::RH: $RI = d + \frac{dl}{a} + \frac{dz}{a} - \frac{2dm}{a}$. Hence $VI = c - d - \frac{dl}{a} + \frac{dz}{a} + \frac{2dm}{a}$; or if $g = c - d - \frac{dl}{a} + \frac{dl}$

. . .

2 d m

 $\frac{2 dm}{a}$; we get $V = g - \frac{dz}{a}$, and therefore $2 g n - \frac{dz}{a}$ $\frac{2ndz}{a}$, will be double the momentum of the arch, which therefore is equal to double the momentum of the pier and counterfort, found in the last problem; that is, czz- $2 clz + \frac{1}{3} cll = 2 gn - \frac{2 n dz}{a}$; and if $q = cl + \frac{n d}{a}$ the square root of this equation will be cz+q=N2 cng - 1 cccl + 99.

EXAMPLE.

Let a = 12, d = c = 9, l = 4; then will n = 92.72, m = 9.23 by problem X. whence g = 10.845, and q = 105.54; these values being substituted into the equation above, gives 28806.5628 for the fum of the terms under the radical fign, whose square root is 169.72, from which subtracting the known term 105.54, and dividing the difference by 9, gives z = 7.13 feet.

This thickness of the piers exceeds that, when the arch is circular by 3 inches only; but as the quantity of masonry in the circular arch is to the quantity in the elliptic arch, as 112 to 92.72; or as 7 to 5.8 nearly; it is evident that the elliptic arch and piers together requires lefs masonry than the circular arch and its piers.

Since then the elliptic arch is rather stronger at its hanches than the circular one, and the middle or its weakest part, sufficiently covered by masonry; and as it is lower, and therefore better covered from the fight of an enemy, it cannot be fo eafily destroyed; it is evident, that it may be used as well, and often with greater advantage, than the circular one.

PROBLEM XIII.

To find the thickness of the piers of a circular arch when there is a wall AEFG above the piers as it happens over the gates of a fortress. Fig. 11.

The same thing being supposed as in the second problem, and calling the thickness A E of the wall d, its height E F, b; then will d b express the area of the wall, which being multiplied by $z - \frac{1}{2}d$, gives d b $z' - \frac{1}{2}d$ d b for its momentum, and as that of the pier is $\frac{1}{2}czz$, that of the arch ng - nz, by the second problem, and therefore czz + 2dbz - ddb = 2ng - 2nz; and if q = n + db; we shall have $cz + q = \sqrt{2cng + cddb + qq}$.

N. B. It must be observed that 4n = rbb - raa, $\frac{3}{4}rm = a + \frac{bb}{a+b}$, and g = c - a + 2m by the second problem.

EXAMPLE.

Let a = 5, b = 7, c = 10, d = 2, b = 20; then will n = 18.852, m = 3.854, g = 12.708, q = 58.852; and performing the operations indicated by the equation we shall find z, or the thickness B C of the piers to be 3 feet 3 inches nearly.

PROBLEM XIV.

To find the thickness of the piers when the arch is elliptical, the rest being the same as before. Fig. 11.

If the height within of the arch be called s; then will $4an = rs \times bb - aa$, $\frac{3}{4}rm = a + \frac{bb}{a+b}$, g = rE 2 $c-s+\frac{2ms}{a}$, by the ninth problem; and 2ng-2nz will be double the momentum of the arch, which being made equal to double the sum of the momentums of the pier and the wall, found in the last problem, gives ezz+2dbz-ddb=2ng-2nz, or $ez+q=\sqrt{2cng}+cdd+qq$ by supposing q=n+db.

EXAMPLE.

Let a=5, b=7, c=10, d=2, b=20, as before, and the height s=4; then will n=15.08, m=3.854, g=12.166, q=55.08; and performing the operations indicated by the equation, we get z=3.154, which being fomething lefs than the former, flews that either of these figures may be used, according as it is judged convenient.

PROBLEM. XV.

To find the thickness of the piers of a circular arch, when they have a given slope CD on the outside. Fig. 12.

From the point C draw C E, and D F parallel to A B, and let the direction L H meet C E in I; then if B F = z, F C = b, and the rest as before, the rectangle c z multiplied by $\frac{1}{2}z + b$, gives $\frac{1}{2}czz + cbz$ for the momentum of the part F A of the pier, and $\frac{1}{3}bbc$ will be the momentum of the part C F D, therefore $czz + 2cbz + \frac{2}{3}cbb = 2ng - 2nz$ by the second problem; and if q = cb + n, the square root of this equation will be $cz + q = \sqrt{2cng - \frac{2}{3}ccbb + qq}$.

The values of m and n are the same as in the fifteenth problem, and g = c - a - b + 2m.

EXAMLE

EXAMPLE.

Let a = 5, b = 7, c = 10, b = 2; then will n = 18.852, m = 3.854 as before, and g = 10.708, q = 38.852 whence the sum of the terms under the radical sign is 5279.5719, whose square root is 72.66, from which subtracting the known term 38.852, and dividing the difference by 10, we get z = 3.38 nearly, and B C equal to 5.38 feet.

PROBLEM XVI.

The same thing being supposed to find the thickness of the piers, when the arch is elliptical.

The fame denomination being supposed as in the fourteenth problem; then the values of m and n are the same here as there; and $g = c - s - \frac{sb}{a} + \frac{2sm}{a}$; therefore, if $q = \frac{sn}{a} + cb$, the rest will be the same as in the last problem, that is $cz + q = \sqrt{2cng} - \frac{s^2}{a^2}ccbb + qq$.

EXAMPLE.

Let a=5, b=7, c=10, s=4, b=2; then will n=15.08, m=3.854, g=10.566, q=32.064; and performing the operations indicated by the equation, we shall have z=2.86; and therefore B C will be 4.86 feet.

PROBLEM XVII.

Suppose a wall KOLM to be continued above the arch with a slope on the outside; to find the thickness K P or L M, the base PO of the slope being given. Fig. 13.

Let PO = d, PL = b; KP = z; and the rest as before; then zb multiplied by $\frac{1}{2}z + d$, gives $\frac{1}{2}bzz +$ dbz for the momentum of the part PM of the pier, and 1 db multiplied by 2 d, gives 1 ddb for the momentum of the other part OPL; the rest being the fame as in the fifteenth problem, and therefore $bzz+2dbz+\frac{2}{3}ddb=2ng-2nz$; and if q=n + db the square root of this equation will be bz + $q = \sqrt{2nbg} - \frac{2}{3}ddbb + qq.$

EXAMPLE.

Let a = 6, b = 8, c = 10; b = 16, d = 3; then will n = 22 nearly, m = 4.486, g = c - a - d +2m = 9.972, q = 70; and finishing the rest of the operations indicated by the problem, we shall have z = 2 feet nearly; and therefore KO, is 4 feet.

Arches, as these are useful in building galleries behind the counterscarps of ditches, such as are made at Bergen-op-zoom, but when they are made pretty large, they become too high; for which reason I would choose to make them elliptical; and as we have all along found that their pressure is rather less than that of the circular ones, on account of their having less weight; the same computations we made in regard to circular arches, will equally hold good in the elliptical ones.

PROBLEM XVIII.

To find the thickness BF or AD, when there is a pressure of earth against the outside slope CD. Fig. 12.

We have shewn in the first section of this work, that the pressure of earth when compared to brick walls, was equivalent to $\frac{2}{2.7}$ parts of the cube of its height; and as these walls are commonly made of bricks, we have no more to do, than to add $\frac{2}{2.7}$ c^3 , to the momentum of the pier found in the seventeenth problem, in order to have the equation $c z + q = \sqrt{2 c ng}$

EXAMPLE:

Let a = 5, b = 7, c = 10, b = 2; then will n = 18.85, m = 3.854, g = 10.708, as before in the fifteenth problem, and q = 38.85; these values being substituted into the equation, and the operations performed as indicated by the equation, gives z = 2 feet nearly, and therefore B C is 4 feet.

PROBLEM XIX.

To find the thickness of the piers with counterforts, when there are two circular arches below, and a small one above. Plate IV. Fig. 14.

The same denomination being supposed as in the eleventh problem, in regard to the lower arch, and let the same lines be drawn in the upper one; then if 0a = s, 0Q or ro = f, Qo or 0r = x; u half the area of the small arch, ob = 2p; then will u = .777 ss and p = .756 s, by the eleventh problem: whence rb or ri = f - 2p; Oi or OH = x - f + 2p; RH

or, R I = a+b+z-x+f-2p; and VI = c-a-b-z+x-f+2p; or if y=c+x+2p-a-b-f; then will V I = y-z, which being multiplied by 2 u, gives 2 uy - 2 u z for double the momentum of the upper arch; this added to 2 ng-2nz double the momentum of the lower arch, and the fum made equal to double the momentum of the pier and counterfort found in the before-mentioned problem, gives $czz+2cbz+\frac{1}{3}cbb=2ng+2uy-2nz-2uz$; whence if q=cb+n+u, the fquare root of this equation will be $cz+q=\sqrt{2cng+2uy-\frac{1}{3}ccbb+qq}$.

EXAMPLE.

Let a = 12, c = s = 8; then if $OQ = f = 14\frac{1}{3}$; that is the lower arch, being three layers of brick thick; and the height $Po = 5\frac{2}{3}$; then will Qo = x = 20; u = 49.728, p = 6.048, y = 9.763, and n = 112, m = 9.072, q = 10.144, by the eleventh problem; hence we get q = 197.728, and 64700.98 for the fum of the terms under the radical fign, whose square root is 254.363; from which substracting the known term 197.728, and dividing the difference by the coefficient, gives z = 7.08 nearly.

N. B. We have supposed the trilinear space S between the lower and upper arch to be empty; that is without masonry, besides a small space between the roof and the pier of the upper arch has been neglected; but as it hardly can make any sensible difference in the thickness of the piers, the reader may depend on that found here to be sufficiently exact for prac-

tice.

PROBLEM XX.

To find the thickness of the piers with counterforts, when there are two small arches below, and a great one above. Fig. 15.

Let ao = s; the height Vr of the lower piers, x; u = .777 ss; p = .756 s; then will ob = 2p, by the eleventh problem; and as or = s + b + z, we get rb or ri = s + b + z - zp, and Vi = x - s - b - z + 2p; or if y = x + 2p - s - b; then will Vi = y - z, therefore 2uy - 2uz, will be twice the momentum of the lower arch.

Now if we suppose the same values as in the eleventh problem, for the upper arch; that is n = .777a a, m = .756 a, g = c + 2m - a - b; then will 2ng - 2nz be twice the momentum of the great arch; and therefore $cz + 2cbz + \frac{1}{3}cbb = 2ng + 2uy - 2nz - 2uy$; whence if q = cb + n + u; the square root of this equation will be $cz + q = \sqrt{2cng + 2cuy} - \frac{1}{3}ccbb + qq$.

EXAMPLE.

Let a = 15, c = 26, x = s = 9, b = 4; then will u = 27.972, p = 4.536, y = 5.072, n = 174.825, m = 11.34; and g = 29.38, q = 306.797; now the operations indicated by the equation being performed, we shall have z = 11.54 feet.

Either of these two last problems may serve to construct large powder magazines in the inland part of the
country, where no enemy can come near them; for
in fortified places, engineers choose to make several
small ones, so that if any one be destroyed by the enemy, the powder might not all be lost, which would
prove the loss of the place at the same time.

If

If the arches were made elliptical instead of circular, they need not be so high, and a great deal of mationry might be saved, as has been shewn in the twelsth problem.

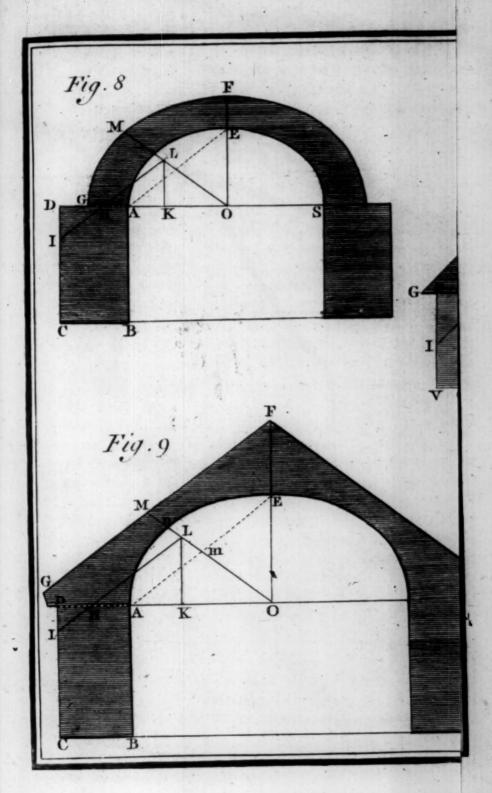
PROBLEM XXI.

Let either the exterior or interior curve of an arch be given to find the other fuch, that all the archstones shall be in equilibrio with each other. Fig. 16.

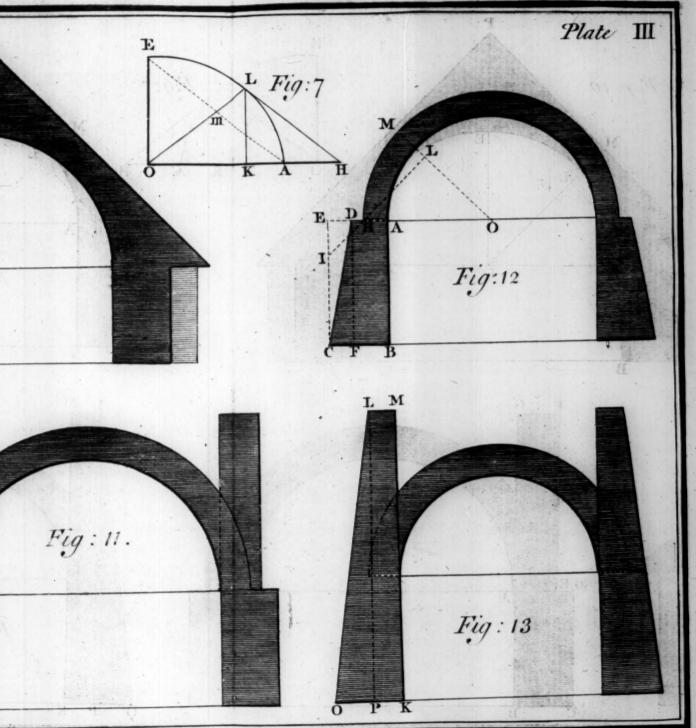
Suppose the interior curve A b c d B to be given, and let all the joints produced, meet in the same point C; from the centers of gravity v, x, y, of the archstones, let the lines vr, xs, yt, be drawn at right angles to the horizontal line DQ drawn at pleasure. and the latter interfecting the joints in E, F, G; then it is evident, that if DE, expresses the weight of the stone w, EF that of the stone x, and FG, that of the stone y; the line CD, will express the force with which the stone v, presses the vertical joint HA; CE, the force with which the stones v, x, press the joint Ib, and CF, the force with which the stones x, y, press the joint Ke: for three powers are in equilibrio with each other, when they are as the fides of a triangle which are perpendicular to their direction; and the fide DE; is perpendicular to the direction v r, of the weight, and the sides CD, CE, perpendicular to the directions of the forces with which the stone v. presses against the joints CH, CI: Again, EF, is perpendicular to the direction xs, of the stone x, and CE, CF, perpendicular to the directions of the forces with which the stone & presses the joints CI, CK; the fame thing is true in regard to any other joint.

Since therefore the same line C E expresses the forces with which the stones x, y, press each other in contrary directions, they destroy each other; again as

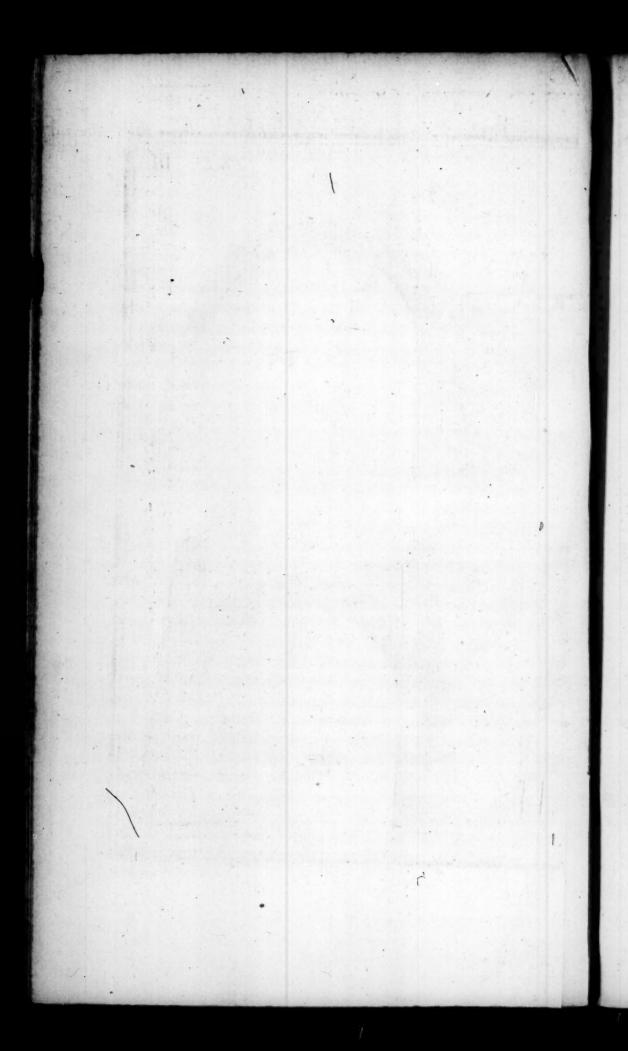
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the same line C F, expresses the forces with which the stones x, y, press each other in contrary directions, they likewise destroy each other; and this is true in regard to any other two adjacent stones. Consequently, if the weights of the stones are to each other as the lines D E, E F, F G, they will be in equilibrio with each other.

Whence, if the curve HIKLM be such that the space AHIb, be always equal to the corresponding triangle CDE, it will be that required, because the height CD, of that triangle is given, its area will be as the base DE.

Now because the circular sectors described by the radii C E, C b, C I, in the same time, are as the squares of these radii, and since those sectors are likewise as the sluxions of the spaces CDE, CAb, CHI; and the difference between the two last is equal to the first, by what has been proved; the difference between the squares of the radii C I, C b, will likewise be equal to the square of the radius C E.

Hence, when CE becomes CD, CI becomes CH and Cb becomes CA: therefore the square of CD is equal to the difference between the squares of the height CA, and CH at the key-stone, which being given, the line DQ will be given in position, and from

thence the curve may be described.

Though we have supposed the interior curve given, yet it is manifest, the solution holds equally good

when the exterior curve is given.

When the interior curve AB, becomes a right line parallel to DQ; the exterior curve HM, will also be a right line parallel to DQ. For because CE will be to Cb as CD to CA in this case; and therefore CE and CI will be in a constant ratio; viz. in the ratio of CD, to the root of the sum of the squares of CD and CA. Which shews that slat ceilings made of stones, so as all the joints meet in the same right line, or slat arches,

arches, if we may call them so, will have all their stones in equilibrio.

PROBLEM XXII.

To construct the exterior curve HM, when the interior AB is given.

Case 1. Let the interior curve A B be a quadrant of a circle, described from the center C with the radius C A or CB; and suppose the thickness A H or length of the key-stone to be given; then if B D be made equal to C H, and through the point D, the indestructions

nite line DQ be drawn parallel to CB.

If after having drawn several radii C I, C K, C L, C M; intersecting D Q in E, F, G; you make one of the legs a e of a right angled triangle a c g, equal to C A; and you take upon the other always c e = C E, c f = C F, c g = C G, and then C I = a e, C K = a f, C L = a g; the curve passing through the points H, I, K, L, will be the required one.

For because CA, CB, are equal by supposition, and CH, BD, by construction, the square of CD will be equal to the difference between the squares of CH, or BD, and CA; and since, CA, ca; CE, ce and CI, ac, are equal, the square of CE or ce, will be equal to the difference between the squares of CI and Cb or CA; consequently the curve HL is

that required.

Fig. 17. Case II. Let the interior curve A B be a circular arc described from the center C, with the radius C B or C A, and let the part A H of the radius drawn through the vertex A, express the given thickness of the arch in that place; on C H as a diameter describe the semi-circumference of a circle H M C; take C M equal to C A, and in C A; C D equal to H M; and draw the indefinite right line D Q parallel to the horizontal line C B; then, after having taken

upon one of the legs ca equal to CA, of a right angled triangle a cg, and upon the other ce, cf; cg, respectively equal to the lines CE, CF, CG; you make CI, CK, CL, equal to the corresponding lines ae, af, ag; the curve line HIKL passing through the

points H, I, K, L, will be the required one.

For because CM, CA and CD, HM are equal by construction; the square of CD is equal to the difference between the squares of CH and CA; and since we have also CA, CE, CI, equal to ca, ce, ci, respectively, it follows that the square of CI is equal to the difference between the squares of CA, and CE; consequently the curve HKL, has been rightly constructed.

This problem has been given at the beginning of the fifth section, book the third of our mathematical treatise, not only for arches generated by a parallel, but likewise for such as are generated by a circular motion; to which the reader is referred, if he wants

to know all the different cases.

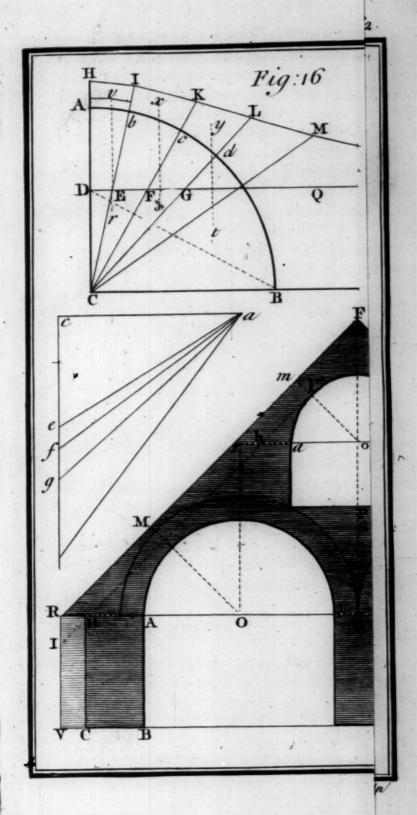
We have endeavoured in this fection to give all the different problems that possibly can happen in practice, relating to this subject; and to render it of more general use, we have given the table of the dimensions of piers for feveral openings of powder magazines; and though the arches are supposed to be circular, yet the fame dimensions may serve for elliptic; or parts of circles. For in all the different kinds of arches, the thickness of the piers of the circular one has always been found the greatest, contrary to the erroneous notions of other authors; who have looked upon the circular one as the strongest and the best, without being able to give any other reason than because all the joints meet in the same point; not considering that the fame thing is so in all arches, made of parts of circles; and as the finest bridges in Europe are built with elliptic arches, it is manifest, that they are able to support the weight with which they are loaded; besides we

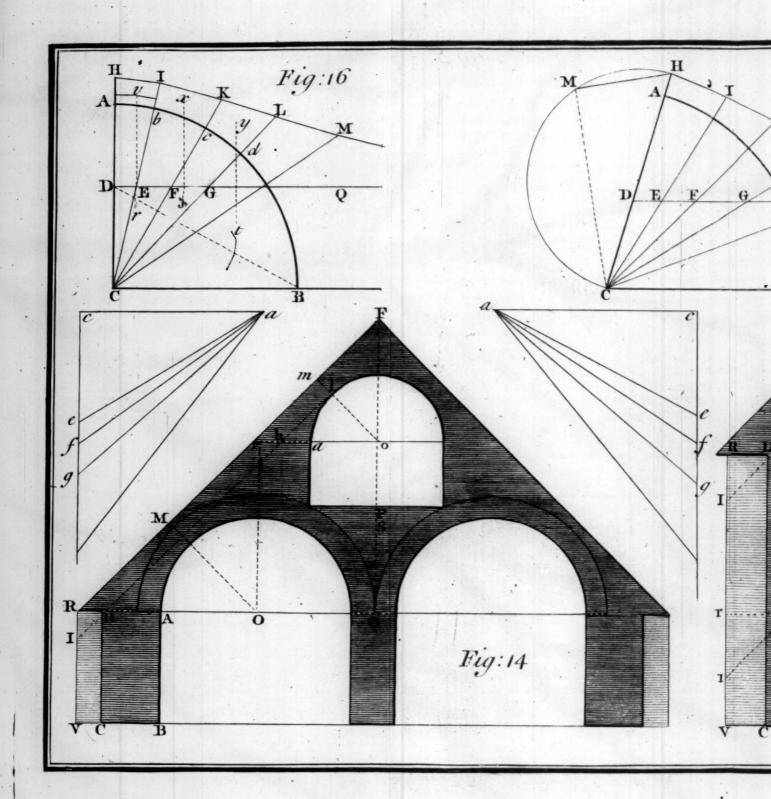
have shewn that they require about one third less mafonry; it must therefore be allowed that they are preferable to the circular ones, especially when it is considered that they look more beautiful to the eye, and their slope is much less; which on the contrary is so very high in Westminster-Bridge, that it is with the utmost difficulty, that heavy loaded carriages can get over it; though in many other respects, one of the finest in Europe.

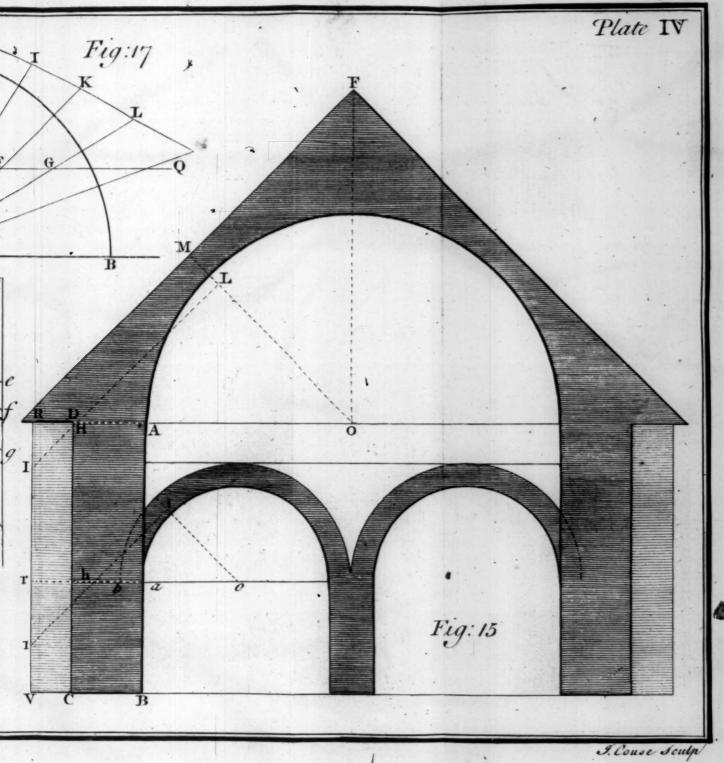
It is also easy to shew that powder-magazines, made with elliptic arches, have the advantage over circular ones in many cases. For in forts, or wherever the ramparts are low, it is impossible that circular powder-magazines can be built to low as not to be feen by the enemy from without, who therefore will endeavour to destroy it as soon as he can, knowing that the surrender of the place depends on it; and if they are built under ground, the powder can at least no longer be kept in it than during a fhort fiege, otherwise it would soon grow damp, and lofe its ftrength: whereas an elliptic arch may be made much lower. Nor will the shells have a greater effect upon their than on the others, because the weakest part is sufficiently covered with mafonry, fo as to be in no danger; and as to the hanches, they are more curvated than the circular ones, and of confequence are stronger in that place.

The two last problems are particularly useful in building of bridges, because the arch-stones being in equilibrio with each other, it is manifest, that the bridge will be stronger, than when they are made in any other form: it is true that the upper part of a bridge cannot be made in this form; unless it is of one arch only; since the passage must have a regular ascent and descent: yet nevertheless, the arch-stones being formed in this manner, and the rest of the side walls being sinished in the usual way, the overplus of the weight is not so very considerable as to produce any very great alteration in respect to the force of the arch stone.

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Besides when a bridge is built otherwise, that is, in the usual manner, the weakest part is loaded with a supernumerary weight, as well as the strongest, whereby it remains still the weakest, and and if that part is more loaded in proportion than the rest, the force to resist that weight must be weakened: on the contrary, the greatest part of the weight being in equilibrio, the remainder cannot cause so great a difference, as in the usual manner.

SECT. III.

Of the STRENGTH and QUALITY of TIMBER.

S the strength and goodness of a building entirely depends on the well proportioning and uniting the whole together, in fuch a manner, as every part thereof may be equally strong; and as we have in the first fection given tables of the thickness of walls which support earth, of any height, and according to any flope, that may be used, as likewise shewn how to find the proper thickness of piers of vaults and arches of any form or opening; it remains now to treat of the different kinds of timber, and of their quality, as well as of their strength, in respect to the different pofition in which they are made use of; especially of those most commonly employed in buildings; in order to render this work as useful as is possible, and thereby enable a young engineer to judge whether a building already excuted, is compleat in all its parts, or when a building is proposed, to make all its parts in due proportion, in such a manner as to be every where equally strong and good, and to avoid all needless expences; which is the point of greatest perfection that can be attained in the art of building.

Of the NATURE and QUALITY of TIMBERS.

Of all the different kinds of timber known in Europe for building, oak is the best in all respects, because when it is well seasoned and dry, it is very tough and hard, it does not split so easy as other timber, and bears a much greater weight than any other whatsoever; when it is used under cover, it never perishes, no more than in water; on the contrary, the older it grows, the harder it becomes; and when it is exposed to the weather, it exceeds all other timber whatsoever for durable-ness.

Fir timber is the next in degree of goodness for building, especially in this country, where they build upon leafes; for it lasts pretty long, when under cover; is very light, and is the cheapest timber that can be bought. It differs from oak in that it wants not fo much feafoning, and therefore no great stock is required before hand: whereas oak must be kept at least a twelve month, and the longer it is kept the better it is; on the contrary, fir is much stronger while the refinous particles are not exhaufted, than when it is very dry, as I have found by feveral experiments: Fir is used for flooring, above all other kind of wood, for wainscoting and the ornamental parts of building within doors; it lasts likewise a great while under water; fome pretend, that it never perishes there, no more than oak.

Elm is the next wood in use, especially here and in France, where it is plenty; because it is very tough and pliable, it is easily worked, and does not easily split, it bears driving of bolts and nails into it better than any other wood: for which reason, it is chiefly used by wheelwrights, and coachmakers, for shafts, naves, fellows, and other such like things, and is almost the only kind of wood used in artillery.

Beach

Beach is also very useful upon many accounts; it is very tough and white when young, and of greatstrength, but liable to warp very much when exposed to the weather, and to be worm-eaten when used within doors; its greatest use is to make planks, bedsteds, chairs, and other houshold goods; and they use it likewise abroad, for axletrees, fellows, and in other wheel-wrights works.

Ash is likewise a very good wood, but very scarce in most parts of Europe; it serves in buildings, or for any other uses where it is skreened from the weather; hand-spikes and oars are chiesly made of it, and indeed it is the only wood that is fit for this and any other

things which require to be tough and pliable.

Wild chesnut timber is by many esteemed to be as good as oak, and seems to have been much used in old buildings; but whether these trees are not so common at present as they have been, or have been found not to answer so well as was imagined, it is certain that this

timber is quite out of use at present.

There are besides many other kinds of woods, which are esteemed useful upon sundry occasions, such as English and Virgina walnut, mahogony, cedar-wood, rose and box-wood, for turners and cabinet-makers works; but as we intend to confine ourselves to those woods only which are used in building; so the following observations, shall extend no farther than to those mentioned above.

Oak may be distinguished into three sorts, viz. that which grows on high gravelly ground, in thick forests, and that which stands on the skirts of forests, in hedges, or any where else, in damp or low ground, where the

air has a free circulation.

That which grows on high gravelly ground, is of a reddish colour, not much unlike that of red sand; it is very brittle, cuts very soft, rots soon, and is neither good for building nor burning; for it never produces

any flame no more than if it was rotten, for which

reasons we shall say no more of it.

That which grows in thick forests, where the air has no free circulation, is very tall and strait, without knots, splits easily, and has a very fine whitish grain; it is therefore very good for building, and for any other carpenters work; it makes exceeding fine planks for all sorts of cabinet works, its natural colour and grain being so beautiful as no other wood can scarcely exceed; but as this wood is very tender and splits easily, it is not good for ship building, and therefore never to be used therein but when no other is to be had.

The third fort, which grows in foft ground, and where the air freely circulates, is very hard and tough; it is never fo tall nor fo strait and smooth as that in thick forests; but is the best that can be used for building of ships; especially if it stands in a wet soil; I have feen fome that grew in a damp meadow ground which was fo tough that the splinters would twist like ropes without breaking; If I mistake not, this is the reason that the English oak is so much better for building ships than any other in Europe; because the soil where it grows is generally damp, and low, and the forests are not fo thick as they are elsewhere, by which the air circulates freely; whereas that which comes from Norway or other parts of Germany stands very thick and in great forests, for which reason it is so tender and fo good for carpenters and joiners work.

Fir may likewise be distinguished into three different sorts; the red, or yellow and the white, and a sort between both. The red is by much the best and the most durable; because it is much more impregnated with rosin or turpentine, which fills it pores, and prevents the water or dampness from entering, and therefore is more able to withstand the weather than the other: I believe that this is the sort from which pitch and tar is extracted; this sort is always used in works that

are exposed to the weather, and for stakes, to drive in the ground, but then it should be burnt in the fire and pitched over while warm, which will preserve it much longer; it has likewise been observed, that it does not decay under water; and it is the best for carpenters work.

The white fort is not for strong nor so durable, but is very good for the inside of a building; such as for shooring, doors, wainscoting, and other such like works; its colour and smoothness of grain makes it preserable for that use to the red sort; as to the third sort, it partakes of both qualities, is neither so strong and durable as the red, nor so beautiful as the white; but serves well enough for all sorts of timber in buildings where it is not exposed to the weather.

As to the elm or ash, I cannot find more than one fort of each; yet it is likely that the different soils in which it grows must make it either tougher, and stronger, or brittle; as likewise that which grows in the open air must be stronger than that which grows in thick forests. For all timber and plants in general grow

strongest in a free air.

Beach, which grows in thick forests, is softer and more brittle than that which grows in the free air; and is very white and tough when young; therefore wheel-wrights use no other than what is very young, and what is no bigger than the scantlings require; especially when used for axletrees, but for fellows they split it into two only; but that which is sawed into planks is much larger, and ought not to be too old, otherwise its grain is very coarse and the wood very brittle.

The goodness of timber not only depends on the soil and situation in which it stands, but likewise on the season in which it is felled; in which architects disagree very much; some will have it felled as soon as its fruit is ripe, others in the spring, and many in autumn or the fall of the leaves: and there are some who pre-

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tend that it should be felled in the increase or full of the moon, imagining that all things increase in the fame manner; but we shall leave these moon-blind gentlemen to their own lunatic judgment, and give the most rational opinions concerning the properest season in which timber ought to be cut. Since fap, as well as any other moistness, is certainly the cause that timber perishes much sooner than it otherwise would do; which appears from timber exposed to the weather not lasting fo long as that which is under cover, as likewife that dry timber, when used, is more durable than that which is fresh cut; this being the case, it is manifest that timber should be felled when there is the least sap in it; which is from the time that the leaves begin to fall to the time that the trees begin to bud; that is from the middle of October to the middle of March; the greatest number of architects agree with us, that this is the best feason for felling timber.

The weather has likewise an influence over timber: for if it be felled in damp and rainy weather, it will not dry, and if it lies too long in this state, the sap will moulder and cause the timber in time to rot: but if the weather be dry and fair, it is plain that the air will draw out the fap and the timber will be more lasting.

When timber is cut, the bark should be taken off and let lie for some time exposed to the sun and weather, and afterwards cut into rough scantlings nearly of the fize they are intended to be used, and then laid up in stakes under cover to secure them against wet weather and the heat of the fun; for the wet hinders it from drying, and the heat of the fun splits it. As oak feems to contain more fap than any other wood, and therefore requires a longer time to dry; the best way to make it foon fit for use, is, as foon as it is cut into fcantlings, to throw it into water; this has been found by experience to draw out the fap much fooner than the weather; for the outfide will in a short time grow as black as ink, which is a certain proof, that

water draws out the sap, in a shorter time than the air. As to the scasoning of any other kind of timbers, I never heard of any other method, than to stake it up in piles, in such a manner as that the air may freely pass between; and to cover it from the rain and the heat of the sun. The time required for drying timber before it is used is very uncertain, some sorts require much more than others: oak must be kept a great while; for the dryer it is, the harder and stronger it grows: this we find by experience: for oak of an old building, or of a ship, is so hard sometimes, that tools will scarcely cut it.

Beach requires likewise a great while drying; and if it is used before it is thoroughly seasoned, it warps very much; and it may be observed in general, that the heavier the wood is the longer it requires to dry: it may be known whether any timber is dry and sound by striking with a hammer pretty hard at one end, and if it sounds clear and distinct, you are certain that it is

both found and dry.

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Fir being a light wood requires less time to dry than any other fort; fir scantling for roofing or for any other use within doors, ought to be half dry only; because it is then strongest, as we have sound by some experiments, which shall be related hereafter; but as to the boards for slooring and wainscoting they ought to be thoroughly dry, otherwise they shrink and spoil the work.

Timber should likewise be cut when of a proper age; for when it is either too young or too old, it will not be so durable. It is said that oak should not be cut under sixty years old, nor above two hundred; whether this is right or not, it is very certain that all timbers should be cut in their prime and nearly when full grown, and before they begin to decay; that will be sooner or later according to the dryness or moistness of the soil in which they grow; as also according to the bigness of the trees,

and the kind of timber: there is therefore no certain rule to go by in felling of timber, but experience and judgment must direct here as well as in many more cases.

Method of computing the strength of Scantlings.

Mr. Parent is the first that we know, who has treated this subject in a scientific manner, and in order to enforce his demonstrations, he made several experiments, with various scantlings of oak and fir; by which he found that the strength of an oaken scantling is to the strength of a fir scantling of the same size as 5 is to 6: fo that according to this experiment, fir wood is stronger than oak; Mr. Belidor has after him treated the fame subject; and made likewise several experiments with oaken scantlings, but as to the experiment in respect to oak and fir, he took the foregoing proportion for granted. The same opinion, that fir is stronger than oak, has prevailed here; for, according to Langley, there was an act of parliament made, after the great fire in London, to fettle the dimensions of fcantlings; in which those of oak are always larger than those of fir: But as this appeared to me contrary to sense and reason, I resolved to try the experiment myself, and found exactly the contrary, as will be feen hereafter. As Mr. Parent was a man of veracity and character, we cannot imagine that he affirmed but what he really found; his oak must have been weaker and the fir stronger, than any I have met with; which led him into this error.

PROBLEM I.

To determine the strength of a scantling whose dimensions are given. Plate VI. Fig. 1.

We suppose that all the fibres of the wood are strait, and of the same strength in its weakest part, that is where it breaks; for it is no matter how they are else-

where; and that the fibres are the same in the same fort of wood; altho' this is not strictly true, yet it is sufficiently near in practice so as to cause no sensible error.

Suppose the scantling ABC to be supported in the middle D by the edge of a triangular block R, and two equal bodies, P, Q, to be suspended at A and C, equally distant from the middle B; of such a weight as

just to break the scantling.

It is evident that the weights P and Q will cause the scantling to bend at first so as to make a kind of a curvilinear angle at B, and then to break in that place, in a section BD perpendicular to either of the sides AC: now as the power or force of these weights is more or less, according as they are suspended farther from or nearer to the point six D; these forces will therefore be in proportion to the products of the weights each multiplied by its respective distance from the section BD; or because the weights and distances are here supposed equal, twice the product of one of the weights P multiplied by its distance, from the section BD, will express the force of these two weights.

Having determined the force of the weights, we are now to determine the relistance or strength of the wood; which is done in the following manner. Let acb represent the section of the scantling; it is evident that this area represents the sum of all the fibres to be torn or broken, and as they are all equal and of the fame strength by supposition; this area will express the fum of the strength of all the fibres: but as the point D, or the base ab of the section is fix; and the directions of the fibres perpendicular to the area acb: the force or relistance of each fibre is equal to the product of its strength multiplied by its distance from the base ab: and therefore the sum of all the fibres placed in the same line df, parallel to the base ab, multiplied by their distance a d, from that base a b, will express their momentum or refistance: What has been proved

in regard to all the fibres placed in the line df, is equally true of all those placed in any other line parallel to the base ab: and therefore the sum of all these products will express the total strength or resistance of the wood: But by a noted property of the center of gravity, the product of the area acb, multiplied by the distance of its center of gravity, from the base ab, will express the total strength or resistance of all the sibres; or that of the whole scantling. Consequently, having the strength of any scantling of the same wood determined by experiment, that of any other may be found.

Fig. 2. If the scantling A C be supported at both ends by the triangular blocks P, Q, and the weight W, hanging in the middle B: then if we suppose the weights P and Q in the last figure to represent the blocks P and Q in this; and as each block supports half the weight W; it is evident that the weight W, multiplied by the distance A B or B C, will express its

momentum or force.

The Same otherwise.

Since the weight W, is suspended in the middle between the point fix; it is evident that each block supports exactly half the weight; and as the power or force of this weight on the blocks P, Q, is as the product of half the weight multiplied by the distance A B or B C of its direction from the point fix: It follows that the whole force of this weight is as twice the product of half the weight W multiplied by A B or B C: or as the whole weight W, multiplied by the distance A B, or B C.

COR. I.

Hence, if the length A C of the scantling between the points fix A, C, be c; the area of the section s; the distance of its center of gravity, from the base d, and the weight W, w; then will $\frac{1}{2}$ cw express the force of the weight W, and ds, the strength of the scantling:

there-

therefore the momentum of the weight is to the momentum of the scantling as $\frac{1}{2}cw$ is to ds; or as w is to $\frac{2ds}{6}$; or if this ratio be given $w = \frac{2ds}{6}$.

From whence we may draw feveral useful confequences, 1. The strengths of two scantlings of the same wood, and of different dimensions, or, which is the same, the weights they will bear, are to each other as the products of their sections multiplied by the distances of the centers of gravity, from the base, divided by their lengths.

2. The strengths of two scantlings of the same wood, which have the same length; are as the products of their sections multiplied by the distances of their centers

of gravity from the base.

3. The strengths of two scantlings of the same wood, which have equal sections, are as the distances of their

centers of gravity, divided by their lengths.

4. The strengths of scantlings of the same wood, whose distances of the centers of gravity of their sections from the base are equal, will be to each other as

their fections divided by their lengths.

N. B. We have taken no notice of the parts of the scantlings at each end, which are beyond the points A, C, and which serve to support them on the blocks; for they cause no difference in respect to their strength: the same thing may be said in respect to the weights of the scantlings, which are so small in proportion to the weights they bear, that there is no occasion to consider them; because there is no geometrical exactness required, nor can be attained in practice. It may also be observed, that when the weight hangs between the point six; the base to which the distance of the center of gravity is referred, is the upper surface AC; since it must open and break first at the lower D; whereas when the point six is between the weight, as in the first figure, it is the lower surface.

COR. II.

Fig. 2. If the fection of the scantling A C be a rectangle placed flat on one of its sides, which we call b, and its height or other side a; then will ab, express the area of the section; and the distance d of its center of gravity from the upper base, will be $\frac{1}{2}a$; therefore the equality found in the first corollary, $w = \frac{2ds}{2}$: becomes here $w = \frac{aab}{2}$. Which shews,

that the strength of a rectangular scantling laying flat on one of its sides; is as the product of the square of its beight

multiplied by its base, and divided by its length.

Hence a deal board of an inch thick and ten inches broad, being placed on its flat side, and then on its narrow side; the force in the first case will be to the force in the second, as unity is to 10. For the force in the first case will be as 10 multiplied by the square of unity; and in the second as unity multipled by the square of 10; that is, as 10 is to 100; or as unity to 10. So that if it bears 50 pounds when it lies flat, it will bear 500 when it lies on the narrow side.

This is the reason that all timbers in buildings are always placed on the smallest side; because they will by this means bear a greater weight, than if they were placed otherwise; and therefore save a good deal of timber; and this in proportion as they are made

higher.

EXAMPLE.

We may from hence likewise find, whether the proportions of scantlings commonly given by carpenters are right according to their length; for which we shall choose the dimensions of fir-girders as appointed by act of parliament, after the great fire of London; which are as follows.

Now

If we suppose, that the dimensions of any one of these scantlings be right, as for example that of 10 feet long; then we may find those of any other, whose length is given, in this manner. Since these scantlings ought to bear the same weight or to be equally strong; the product of the square 100 of the height multiplied by the base 8, gives 800, which being divided by the length 10 feet or 120 inches,

Length	Breadth	Height
10	. 8	10
12	8.5	10
14	9	10.5
16	9.5	10.5
18	10	11
20	11	12
22	11.5	13
24	12	14

gives 2,0 which expresses the strength of the given scantling, and therefore must be equal to the dimen-

fions of any other;
$$\frac{a}{b} = \frac{20}{3}$$
.

If we suppose the length c to be 12 feet or 144 inches, and the height a, 10 inches; then by sub-stituting these values into the last equality, it becomes

$$\frac{20}{3} = \frac{100 b}{144}$$
; and if 20 be multiplied by 144, and 3

by 100; the former product divided by the latter gives 9.6 inches for the base b, of the scantling; which is 1.1 inches more than that above.

In the same manner may be found the dimensions of all the other scantlings, whose lengths and heights are the same, which gives the following table.

The breadths of the same scantlings being compared, it appears that those whose lengths are 12, 14, 16, 18, 20, are too little in the former table, and those of 22 and 24 feet long, too great: which shews that practice alone is not sufficient to determine the proper size of scantlings; and that without the application of mathematical principles, no great improvement can be expected in any me-

Length	Breadth	Height
10	8	10
12	9.6	10
14	10.1	10.5
16	11.6	105
18	11.9	TI
20	11	12
22	9	13
24	9.8	14
chanica		

chanical art whatever; notwithstanding what ignorant workmen infinuate.

As to the dimensions of oak scantlings given by workmen, we shall not compare them, till we have given the following experiments, we made with great accuracy, and upon which the reader may depend.

EXPERIMENT I.

The sticks used in this experiment were 24.5 inches long from one end to the other, and half an inch foure; they were laid on two truffes well foured, and flood 20 inches distant from each other; so that the length of the sticks is to be considered as no more than 20 inches; the remaining part ferving only to rest upon; the weights were fuspended in the middle by a string, such as just to break the sticks, and are as marked underneath.

> 69 lb. Two dry oak flicks { 50. A dry fir flick 46. A dry elm stick 31.

The first oak stick feems to have been thorough dry; I had it from the dock, and likely was taken out of an old ship; the second I had out of the warren as dry as could be had; the grain of the wood was strait in both; but that of the first was finer than that of the fecond, and of a deeper colour; which, if I am not mistaken, denotes, that the tree was in its prime when felled.

The fir stick did not bend so much before it broke as the oak; it was of the reddish kind, and the strongest that could be found: As to the elm it bent very much before it broke; and as this last is so weak, we did not think proper to try any more of it in the following experiments.

EXPER'IMENT II.

Two oak sticks cut out of an old axletree \{ \begin{array}{l} 55 \\ 54. \\ An oak stick cut out of a spoke of a wheel \quad 56.5 \\ \text{Three fir sticks out of the same piece} \{ \begin{array}{l} 36.5 \\ 36 \\ 36 \end{array} \]

A fir stick of an equal section, whose base } 42.5.

The oak sticks in this experiment had a coarser grain than those in the former, and seem to have been of an older tree; as to the fir sticks no difference could be perceived, either in the grain, colour, or any thing

elfe, from the former.

By these experiments it plainly appears, that oak is stronger than fir, contrary to those made by Mr. Parent, and common practice: for the weakest oak is stronger than the strongest fir in the first experiment: in proportion as 25 to 23: But those in the second experiment, make a much greater difference, viz. as 54 to 36; or as 3 to 2: And if the strongest oak stick in the sirst experiment be compared to the strongest fir; the proportion will be as 69 to 46; or as 23 to 15; or as 3 to 2; that is the same as before; which is very considerable, and therefore deserves to be taken notice of.

As the strength of the same kind of wood varies very much, it is impossible ever to come to an exact knowledge of the just proportion between the strength of oak and fir; but we are certain that oak is the

strongest of the two.

As the least porportion we have found, viz. that of 25 to 23, is very nearly equal to that of 9 to 8; so by making the oak scantlings less in that proportion, there will be no danger of their being too small, only it must be noted, that oak ought to have been cut a twelvemonth before it is used, as we have observed before, whereas

whereas fir does not require above fix months feafon-

As the last fir stick had the same length, and an equal fection with the others, it is plain that its strength is to that of one of the others, as the height of the first is to the height of the second, by what has been proved before: and if x be the height of the last stick, then

will $\frac{2x}{a}$, be its base, and $\frac{2xx}{a}$ = ab, or because a and

b are each $\frac{1}{2}$ or .5: we have $\frac{2 \times x}{2} = .25$; or $x \times = .25$

:375; whose square root gives x = .611, or 6 nearly; that is the strength of the last stick is to that of any of the former as 6 is to 5: Now if we fay as 6 is to 5, fo is the weight 42.5, this stick bore, to the weight 35.4 nearly, whereas it bore the weight of 36 pounds; this difference is inconsiderable, considering that the weight cannot be fo nicely observed, to come within 2 or 3 ounces; and belides, the flicks were not so exactly of the given dimensions, as that no difference might arise from thence. So that this experiment, considering formall a difference, answered the theory pretty nearly.

Having determined the proportion between the frength of oak and fir fcantlings, it remains now to determine the dimensions of oak girders, from those of fir; in which we suppose that a scantling of fir, being 10 feet in length, 8 inches in breadth, and 10 high, is sufficiently strong, and from thence all the fucceeding ones both of fir and oak have been deter-

mined.

TABLE I. Containing the dimensions of girders.

The lengths are expressed in feet, and the breadths and heights in inches.

F	FIR.		
Length	Breadth	Height	
10	8	10	
12	8	1.1	
14	9	11.1	
16	9	11.9	
18	10	12	
*20	10	126	
2.23	11	12.6	
24	11	13.2	

C) A]	K.
Length	Breadth	Height
10	7	10
12-	7	11
14	8	11.1
16	8	11.9
18	9	11.9
20	9	12.5
22	.10	12.5
24	10	13

For, according to the equality $w = \frac{aab}{c}$, above, if c = 10 feet or 120 inches, a = 10, b = 8; then will $w = \frac{20}{3}$; and $\frac{20}{3} = \frac{aab}{c}$; now if c = 12 feet or 144 inches, b = 8; then will $\frac{20}{3} = \frac{8aa}{144}$ or aa = 120, whose square root is 11 nearly, for the square of 11 is 121. In the same manner are sound all the fir scantlings: And if we reduce $\frac{20}{3}$, in the proportion as 9 to 8; we shall have $\frac{160}{27}$ for the strength of oak scantlings: that is $\frac{160}{27} = \frac{aab}{c}$.

Hence if c = 10 feet, b = 7; then will $\frac{160}{27} = \frac{7aa}{120}$ or a = 101, whose square root is 10 nearly; which is the same as in the table; the rest of the oak scantlings are found in the same manner.

TABLE

TABLE II. Containing the dimensions of fir joists common and trimming.

-					
C	m	m	0	n	

Length	Breadth	Height
6	2	8
8	2.5	8.2
9	3	8
10	3	8.4
11	3.5	8.1
12	1 4	8

Trimming.

Length	Breadth	Height
5	3	7
6	3	7.6
7	3.5	7.6
8	4	76
9	4.5	7.6
.10.	5	7.6

The dimensions of the first scantlings in each table, are supposed to be of a sufficient strength, and the rest are from thence determined. For if c = 6 feet or 72 inches, b = 2, and a = 8; then will $\frac{16}{9} = \frac{a a b}{c}$; and if c = 8 feet, b = 2.5; then will $\frac{16}{3} = \frac{2.5 a a}{96}$; or aa = 68.26, whose square root is 8.2; the same as above.

But if we suppose that c = 5 feet, b = 3, and a = 7; then will $\frac{49}{29} = \frac{a \ a \ b}{c}$, by which the second table is constructed. For if c = 6 feet, b = 3; then will $\frac{49}{20} = \frac{3 \ a \ a}{7^2}$, or aa = 58.8; whose square root is 7.6, nearly.

TABLE III. Containing the dimensions of fir bridging joists.

In fmall Buildings.

T.	1	D:1	1:	
ın	large	Buil	dings	

Length	Breadth	Height
.6	2.5	5
7	2.5	5.5
8	2.5	5.9
9.	3	5.6
10	3	6
11	3	6.2
12	3	6.5

Length	Breadth	Height
6	3	5.4
7	3_	5.8
. 8	3	6.2
9	3	6.6
10	3	6.7
11	3.5	6.8
12	3.5	7.1

If we suppose that c = 6 feet, b = 2.5, a = 5; then will $\frac{12.5}{14.4} = \frac{a a b}{c}$, by which the second table is constructed, and if c = 6 feet, b = 3, a = 5.4, then will $\frac{7.29}{6} = \frac{a a b}{c}$, by which the second table is constructed. It may be observed that carpenters always allow larger scant-

be observed that carpenters always allow larger scantlings in large buildings than in small ones, and they must be stronger, than barely to support the weight they are to sustain.

N. B. The reader will find the feveral names of the timbers mentioned in these tables explained in the latter part of this work, where we treat of timber frames and roofings.

TABLE IV. Containing the dimensions of tie beams,

	FIF.			
L	enght	Breauth	Height	
-	12	6	8	
1	16	7	8.5	
1.	20	7	9.5	
	24	7	10.4	
	28	8	10.5	
	22	8	11.3	
	36	8	12	
1	40	9	12	
1	14	9	12.3	

	Oak.	
Lenght	Breadth	Height
12	5	8.2
16	6	8.7
20	U	9.7
24	6	10.6
28	7	106
32	7	11.3
36	7	12
40	8	12
44	8	126

By following the same method as before, we shall find $\frac{s}{3} = \frac{a a b}{c}$, for the equation by which the first table is constructed; and $\frac{7}{3} = \frac{a a b}{c}$ nearly, for that by which the second is constructed.

TABLE V. Containing the dimensions of the principal rafters.

Of Fir.

Lenght	Breadth	Height
18	4	5.5
20	4	6.1
22	4	6.4
24	5	6
26	5	6.2
28	5	6.4
30	5	6.7
32	5	6.9
34	5.	7.1
36	5	.7.3
38	5	75
40	5	7.7

Of Oak.

Lergth	Breadth	Height
18	3	5.3
20	4	5.7
22	4	6
24	4	6.3
26	4	6.5
28	4	6.8
30	4	7
32	5	6.5
34	5	6.7
36	5	6.9
38	5	7.1
40	5	7.3

Authors give various dimensions to the principal rafters; Mr. Smith gives one sort, Mr. Price another, and Mr. Langley will have them to to be stronger at the bottom than above; but, his is not followed by any workmen, as I am told; besides Mr. Price says, that they should be stronger in large buildings than in small ones, although of the same length; I see no reason for any such practice; their strength ought rather to be in proportion to the weight of the covering, and to the distances they are from each other: as authors do not agree in regard to the strength of rafters, we have chose a medium between them, for the dimensions of the first scantling of each table.

TABLE VI. Containing the dimensions of small rafters.

Of Fir.

nc	A 1	
()t	Oak.	
01	Car.	

Length	Breadth	Height
9	2.3	4.7
10	2.4	4.9
11	2.5	5
12	2.6	5.2
13	2.7	5.4
14	2.8	5.5
15,	2.8	5.6
16	2.9	5.8
17	2.9	59
18	3	6
19	3	6.1
20	3.1	6.2

Lanash	1Deer deb	TT - 1
Length	Breadth	rieigh
9	2.3	4.6
10	2.3	4.7
11,	2.4	4.8
12	2.5	5
13	2.6	5.2
14	2.6	5.3
15	2.7	5.4
16	2.8	5.5
17	2.8	5.6
18	2.9	5.8
19	3	5.8
20	3	6

These are the tables commonly given by carpenters and architects, concerning the dimensions of scantlings; but as their exactness depend on the dimensions taken out of other authors, of the first scantling of each ta-

of

ble, so that if they are not right, all the rest are likewise salse; but as we always took the shortest, which are the likeliest to have been used, and sound to be of a sufficient strength, it is presumed that the other scantlings given here are all strong enough; and perhaps more to than they need to be.

EXAMPLE II.

Fig. 5. Let a rectangular scantling be placed edgeways, so that B D be the diagonal, and let the sides still be represented by a, and b; then will $d = \frac{1}{2}\sqrt{aa+bb}$; and therefore the equation $w = \frac{2ds}{c}$; becomes $w = \frac{2abd}{c}$ in this case; and since d or the diagonal B D is greater than any one of the sides; the scantling will bear a greater weight in this position, than, if it were placed flat on one of the sides: But as wood will yield at the point B, by the force of the weight suspended there; the strength will be found something less than is expressed by this equation.

EXAMPLE.

Let the section of the scantling be a circle, whose diameter is a, and area s; then will $w = \frac{as}{c}$ be the equation, which shews that the force of a cylindric scantling, is expressed by the area of its section multiplied by its diameter, and divided by its length; and therefore is to the force of a scantling whose section is the circumscribed square; as the area of the circle to that of the circumscribed square.

It is also manifest, that the strength of a triangular scantling, when laid flat on the base, is double the strength when the edge is undermost, so as the base be parallel to the horizon. For the distance of the center

Sect. 3. FORTIFICATION. of gravity from the base is half the distance of that center from the vertex.

PROBLEM II.

To find the weight a scantling AC will bear, when it is suspended any where between the points A and C. Fig. 3.

Since the block P, which is nearest to the point of suspension B, supports a greater part of the weight than the block Q, which is farthest from it; we are to find the parts of the weight which each bears, in order to folve the problem. By the known rules of mechanics, the whole length AC of the scantling is to any part A B or B C, as the whole weight W, is to the part supported by the block Q or P. If therefore we call AB, m, BC, n, and the rest as before; we have $c:n::w:\frac{nw}{m}$ = to the part supported by the block P; and $c:m::w:\frac{mw}{c}$ = to the part supported by the block Q: Whence these weights being multiplied by their respective distances A B, B C, give $\frac{n m w}{c}$, $\frac{n m w}{c}$, for their momentums, and the fum $\frac{2 m n w}{m}$ must be equal to the strength ds of the wood by problem the first, which gives $\frac{2 n m w}{6} = d s$, or $w = \frac{c d s}{2 nm}$ for the weight required.

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If we suppose the weight to be suspended in the middle, then will $n = m = \frac{1}{2}c$; and the last equation becomes $w = \frac{2 ds}{s}$; which is the same as in the first. problem.

If

If the scantling A C is rectangular, and its base be b, altitude a; then will ab = s, and $d = \frac{1}{2}a$; these values being instituted into the equality above, gives aabc

 $w = \frac{aabc}{4nm}.$

Since, when the weight is suspended in the middle, we have $w = \frac{a \cdot a \cdot b}{c}$; it is evident, that the strength of the scantling when the weight is suspended in the middle, is to the strength of the same scantling, when the weight is suspended nearer to one end than the other, as 4nm is to cc: Consequently the weight any scantling will bear when suspended in the middle being known; the weight which that scantling would support at any distance from either end, may be found by the last proportion.

EXAMPLE.

Let AC be 20 inches, and the section half an inch square; suppose the scantling to be of fir, such as we used in the second experiment, which bore 36 pounds; and let AB be 5 inches; then will BC be 15; whence 4nm = 300, and cc = 400; therefore 300:400:36:48 = 10 the weight the same scantling would bear being suspended at the distance of 5 inches from either end.

This shews, that in buildings, it should be avoided as much as possible, to place the weight in the middle of a beam, such as king posts are in roofs; and therefore it is more advantageous to use prick-posts instead of king-posts; this is likewise what carpenters do in most buildings where there is no partition wall to support the beam in the middle.

Fig. 4. It may likewise be observed, that a scantling A C of the same strength with the former, will bear two weights W, W, each of 48 pounds, when their distances A E, F C from the ends are 5 inches: 3.

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this appears plain from the foregoing example, because these weights will cause the scantling to break in two places.

Mr. Parent is the first we know, that has shewn how to cut the strongest scantling possible, out of a given tree: As this may be useful in practice, because timber merchants are sensible that the square is the greatest figure that can be inscribed in a given circle, and for which reason they chuse to make all their timbers square, as being most advantageous to them; we shall insert the following.

PROBLEM III.

Let AFBE, be the circumference of a tree out of which it is proposed to cut the strongest rectangular scantling that is possible. Fig. 8.

Draw the diameter D G, at right angles to the parallel fides AE, BF, interfecting AE in P; then because the strength of the scantling is expressed by A E X A E X A F, as has been proved in the first problem; but by the property of the circle, we have A Pl2= $DP \times PG$, and AF = 2CP; therefore the strength of the scantling will likewise be expressed by 8 DPx PGxCP; now because this expression is the greatest of all possible, when the square of CP is one third of the square of CD, by article 247 of our Elements of mathematics; or which is the same, when the square of the base A F is one half of the square of the altitude A E: For because the sum of the squares of CP and PA, is equal to the square of the radius CD, by the property of the circle: and therefore if the square of CP is one third; the square of PA will be the two thirds of that square, consequently, the square of AP must be double the square of CP; or the square of A E double the square of A F.

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Fig. 7. Divide the diameter A B of the tree into three equal parts at C and D; and from the points C and D of division, draw D E perpendicular above, and C F, below the diameter; then if the points of intersections E, F, of these lines and the circumference, are joined to the extremities A, B of the diameter; the rectangle A E B F, will be the greatest that can be inscribed in that circle.

For because A D is two thirds, and D B one third of the diameter A B by construction, the square of DE, will be two ninths, and the square of A D sour ninths of the square of the diameter; therefore the square of A D is double the square of DE; and by the similarity of the triangles A DE, A E B; the square of A E is double the square of E B.

It has been observed a great while, that when the base of a scantling is to its height as 5 to 7; that it was nearly the strongest of all the scantlings whose sections are equal, and inscribed in a circle; and because the square of 5 is 25, and that of 7 is 49; the former being nearly half the latter, exceeding by an unit only; this observation perfectly agrees with what has been proved in the last problem.

PROBLEM IV.

If a scantling be supported at the ends by two blocks P, Q, not placed in the same horizontal line, and the weight suspended in the middle, to find the strength of this scantling. Fig. 9.

From the point C in the vertical line, passing through the edge of the highest block Q, draw CE parallel to the horizon, meeting the direction of the weight in L, and the vertical line drawn through the edge

edge of the lower block P in E; then because it has been proved in the first problem, that the weight W multiplied by the distance of its direction from one of the points fix, expresses the momentum or force of that weight: that is W \times C L expresses the momentum: but the force of the wood has likewise been proved to be as the product of the section multiplied by the distance of its center of gravity from the point B. Therefore if we call C E, n, and the rest as before; we shall have $\frac{1}{2}n w = ds$, by what has been proved before, consequently $w = \frac{2 ds}{n}$.

Hence, because we have $w = \frac{2 d s}{s}$, when the scant-

ling lies horizontally, and c expresses its length: the strengths of the scantling in these different positions are to each other reciprocally as the distances of the directions of the weight from one of the points six; that is the strength of the scantling in this oblique position is to its strength in a horizontal position, as C B is to C L; or as the radius is to the cosine of the inclination L C B.

For example, if the scantling A C bears a weight of 36 pounds, when placed horizontally; to find what weight it will bear when it makes an angle of 15 degrees; then because the cosine 9659 of that angle is to the radius 10000, as the weight 36 is to a fourth

term, which gives 37.2 pounds nearly.

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But if the angle of inclination is 60 degrees; then because the consine of this angle is to the radius as 5 is to 10; the scantling will support a weight 72 double the former. Whence it is plain, that as the angle of inclination increases, so the strength of the scantling increases likewise: and when that angle becomes a right one, or the scantling becomes upright, its strength is not to be expressed. But because the sibres of wood are not always strait, and give way when pressed very hard,

hard, it is very pollible to press an upright scantling

fo as to give way and break.

This problem is useful in finding the respective ftrengths of fcantlings which are joined together, with different angles of inclinations; fuch as in the roofing of any building, and thereby fave unnecessary expences.

Fig. 10. It is not sufficient that the strength of fcantlings may be found, there are likewise some positions that are more advantageous than others, which ought likewise to be known. For instance, let ABC be the pitch of a roof, and a strut EF, is to be placed fo as to support the rafter A B in the best manner: I fay that when EF, is the base of an isosceles triangle AEF; or, which is the fame, when it makes equal angles with the tie-beam AC, and the rafter A B, it is in its most advantageous position; for the strength of this piece is proportional to the distance of its direction from the point fix A; but the perpendicular drawn from the point A to the base E F is the greatest of all when the triangle is isosceles: Consequently, this is the best position that the piece can have.

But if the strength of the tie-beam AC, is to be confidered, and there is no party wall to support it in the middle, the case is otherwise; for in that case the piece must be upright as GH; because the nearer the point G approaches the point fix C, the less strength is required to support the piece G H. Hence it is manifest, that a fcantling may be most advantageously placed in respect to its own strength, but not in regard to other scantlings to which it is joined: And consequently, in the framing of timbers for a building, not only regard must be had to the strength of the scantlings themselves

but likewise to those to which they are framed.

PROBLEM V.

To find the strength of the principal rafters AB, BC, so as to be proportional to that of the tiebeam AC. Fig. 10.

Let the base of the rafters be n, and their height 2n, that is double the base as they commonly are made: Let the base of the tie-beam A C be b, its altitude a, and half its length A D, n; then the strength of the rafter will be expressed by $\frac{4n}{n}$ by the last problem;

and that of the tie-beam by $\frac{aab}{2n}$ by the first problem;

therefore $\frac{4x^3}{n} = \frac{a \ a \ b}{2 \ n}$ by supposition, or $8x^3 = a \ a \ b$;

whence the cube root will be $2 \times = \sqrt[3]{a a b}$.

Hence because the length A B of the rafters does not enter into the equation; it is evident, that whatever the pitch is, the cube root of the base of the tie-beam multiplied by the square of its height, will always give the height of the rafter. For example, a fir tie-beam of 12 feet long, is made 6 inches by 8, according to the tables given before; then because a = 8, b = 6; we get a a b = 384, whose cube root is 7.2 inches nearly; for the height of the rafters, and hence we get 3.6 inches for the base.

If the beam AC be 24 feet long; then the base is 7 and height 10.4, according to the foregoing tables: whence b = 7, a = 10.4; and hence aab = 757.12, whose cube root gives 9.1 inches nearly, for the height,

and 4.5 for the base of the rafters.

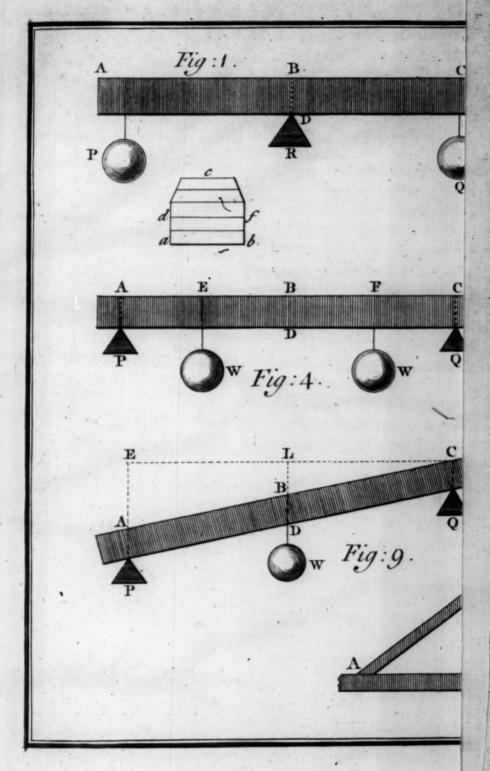
In the true pitch of a roof the principal rafters are the three fourths of the tie-beam, which being here supposed to be 24 feet long; and therefore the length of the principal rafters, will be 18; and according to the fifth table, their base is 4 and height 5.5; which dimensions

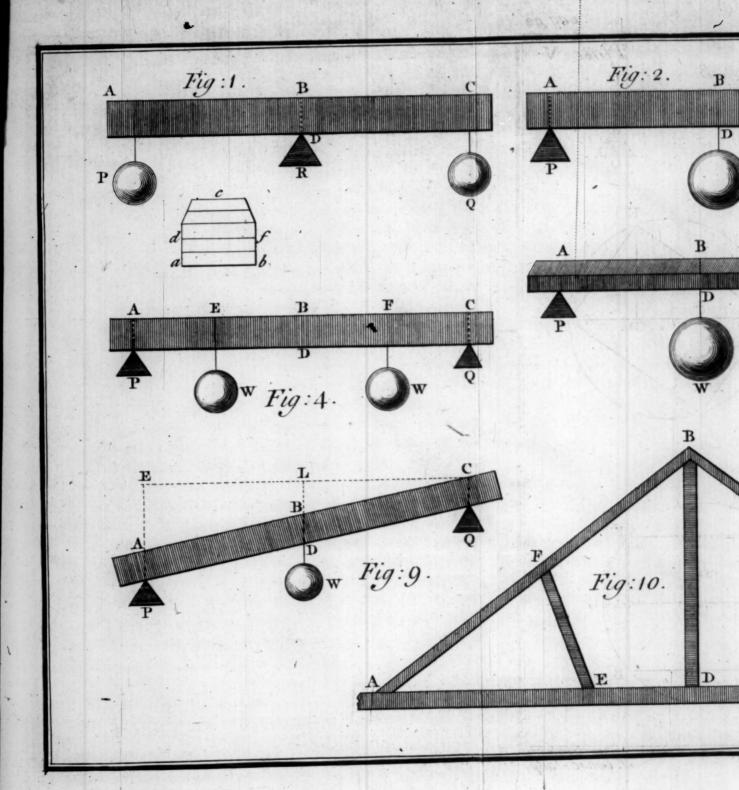
dimensions are therefore in no proportion to that of the tie-beams. But then it must be considered, that the rafters are always supported by struts or uprights, which, bearing a part of the roof, strengthens them and weakens the tie-beam.

These are nearly all the different problems we could thinks of, that may be useful in framing of timber works; which the reader ought to be well acquainted with, if he designs to make any progress in the art of building; for what is found in most authors on architecture, relates chiefly to practice, which alone is not sufficient to make any improvements: and it is no wonder, that for so many ages as architecture has been cultivated, there has been so little progress made, since very few had any knowledge of those parts of the mathematics, which are necessary to be known, and therefore I advise the reader to make himself master of them; before he enters upon the practice.

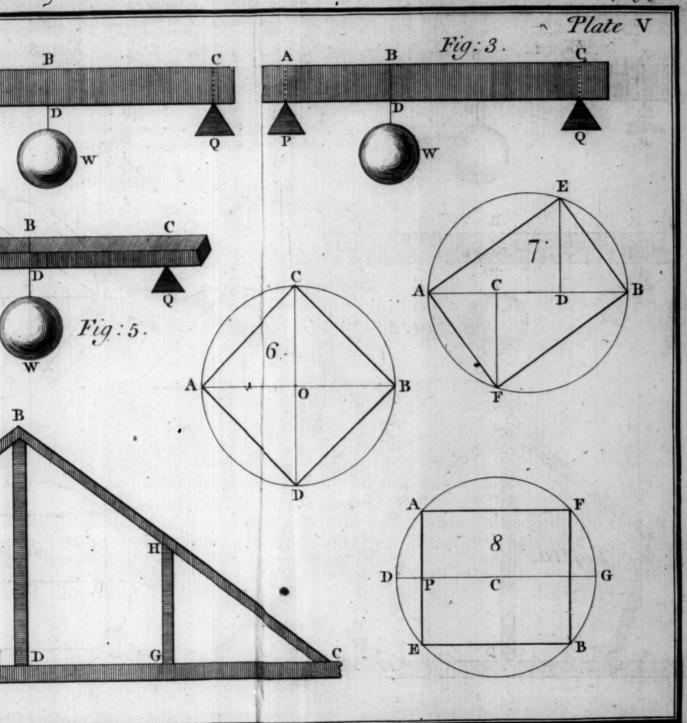
The theory of timber given here is of very great use both in civil and military architecture, since we are taught thereby not only how to find the proper strength of scantlings in respect to their length, when placed in an horizontal position, but likewise when framed together, according to any angle of inclination, which practice alone could never have determined, to any degree of exactness: the entering into all the different applications that may happen in practice, would require more room than can be allowed in so small a tract as this; for which reason, we shall give as much of it hereaster, as will be sufficient to young engineers, for

whom this work has been published.





B



J. Couse Soulp.

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PARTII.

Containing the Knowledge of the Materials, their Properties, Qualities, and Manner of using them.

BEFORE we enter into the manner of building the feveral works of a fortress, it is necessary to be particularly acquainted with the several materials of which they are composed, in order to distinguish their good and bad qualities, how to prepare and use them, in the best manner, that the works may be durable and lasting; which ought in all such great undertakings be the principal view of an engineer, who is answerable for its success or miscarriage; this he is by no means able to perform without having a thorough knowledge of all the materials of which it is composed: But as these materials differ in their qualities in different parts of the country, where they are to be used; we shall explain first their general properties, and afterwards in what they differ in different places.

SECT. I.

Of the Quality of Stones such as are used in Buildings.

STONES may be distinguished into two sorts, that is into hard and soft; the hard stone, is that which is exposed to the open air, such as rocks, and those which lie loose upon the surface of the earth, and

in separate blocks: the soft stone is that which is found in quarries and under ground; it is undoubtedly true that the hardest stones make the most lasting works; but as there is seldom a sufficient quantity of them, to build the whole fortification, the best serve in the facings of the works, in the soundations, and wherever, the works are bathed with water: for as the soundations support a great weight, they must be made strong accordingly, or else the works will soon be destroyed: therefore the outside of rocks or the upper stones of quarries, being the hardest, are used for that purpose.

Altho the stones of some quarries are very soft and eafily worked when they are fresh taken out, yet when exposed for some time in the open air, become very hard and durable: therefore an engineer, who is employed in any particular place, may at all times know by the inhabitants, which of the quarries, if feveral, produces the best stones; he may likewise find by the buildings of fome standing, the quality of them; this will enable him to referve the best for such works as require most strength, and the foster fort may be used in the infide of the walls: but where there is but one quarry, he must examine whether some part is not better than others; in short, a judicious choice of the materials, properly adapted, may render a building more lasting, than using them promiscuously, as careless builders frequently do.

But if it happens that there is no quarry which has been opened long enough, so as to judge of the goodness of the stones, or where he is obliged to open new ones, he ought to expose the stones for a twelve month, at least, to the weather, both to heat and cold, before he employs them; then if they do not splinter after a frost, or do not moulder into dirt, when rubbed, he may be assured that the stone is good: and on the contrary, if they splinter or moulder, it is a certain proof of

their bad quality.

Mr. Boyle pretends, as he has been informed by workmen, that there is a fap in stones as well as in timber, by which the same fort of stone and taken out of the fame quarry, if dug at one season, will moulder away in a very few winters; whereas if they are dug at another season, it will result the weather for a great many years, not to fay ages: but as he does not mention what feafon is best, nor gives any reason for what he advances; no rule can be gathered from what he fays: we may fay thus much, that they should always be dug in the fpring, fo as they may have time to dry before the cold weather comes in: for the heat of the fun will extract the greatest part of the moisture which otherwise expands in frosty weather, causes the stone to splinter, as it has been observed to do; altho' the stone is otherwife hard and good.

The same author says likewise, that some sort of stones will decay in a few years; and others will not attain their full hardness in thirty or forty years, nay even in a much longer time; and besides that there are quarries in some places of solid and useful stones, that, though being dug at a certain season of the year, prove good and lasting, yet when employed in a wrong time, moulder away, and perish in a sew years. That there appears a seminal spirit, if I may call it so, in stone, is very probable; but what effect it has upon the stone when separated from its stock is very uncertain, and therefore cannot be known but by a strict inquiry of a long course of practice.

The manner of drawing the stones out of quarries, requires particular notice to be taken: for almost all stones lie in horizontal beds or stratas; that is, they cleave in that direction; and they have likewise a breaking one, which is perpendicular to the former, both which directions must be observed. The method of drawing stones out of quarries is thus: having uncoped it; that is, having removed the earth from the stone, it must be observed where it will cleave, and there drive in a good many wedges gradually together, till

next proceed to break it, which is performed in this manner; you mark the breadth of the stone with a ruler, and then cut a small chanel in which a number of wedges are drove, from four to six inches distant from each other, slowly and all together, lest the stone should break across and not according to the mark; but it may be observed, that this method is not always to be used, because all the parts of a stone are not always of an equal hardness, but in some places it may be hard and in others soft, which is perceived in the cutting the chanel, and those wedges which are in the softer parts, are drove deeper than the other, in such a manner that all the wedges may press alike: this has been found by experience to be the best way of breaking stones.

Having thus broke them in length, which the stonecutters can do, as they pretend, to any fize within less than half an inch, which is sufficient for any rough stone; then you proceed to break them in breadth in the same manner as before in length. When these precautions are taken, the first expence is greater than if they were broke any how; but then there is little waste in the stones, the workmanship will be less, and saves

expences in the carriage.

But when the stone is very hard they will not cleave fo easily; for the workmen are then obliged to cut a pretty deep chanel, and so wide as to lay two iron bars in it, and to leave room besides for the wedges to be drove in between them, by which means the stones may

be broken, which could not be done otherwise.

The workmen make at other times use of gunpowder to blow them up; which is performed in this manner: they make a small hole with a chisse, of an inch or a little more in diameter, sometimes vertically, and at others horizontally, as is most convenient, and as deep as they want to blow up stones; this hole being cleaned clear of all dust and rubbish, they put in some powder, then the rest of the cavity is filled with the same stone beat into dust, and rammed in as strongly as they can; in doing that they place a wire in the middle to preserve a vent to set fire to the powder, and the rammer is hollow in the middle to receive this wire; this being done, and the powder fired, breaks off as much stone as they please; and the pieces are broken into such blocks as are wanted. This way of breaking them is much cheaper than any other, but wastes a great deal more stone, for which reason it is never used but where it is so plenty as that the small pieces are no loss, and which may serve as rubble to fill up the insides of walls.

There are several kinds of stone; as marble, fire stone, purbeck stone, ray stone, alabaster, free stone and common stone: of each we shall say something in their order.

Marble is of various colours, as white, black, grey, green, some varied with spots and veins like the roots of trees; their nature and use are too well known to require any explanation; the marble sound in *England* is mostly black, and so very hard and difficult to polish, that very little use is made of it, except to burn and make lime; which is frequently done about *Plymouth*, where scarcely any other lime is used, as I am informed.

The fire stone comes from Reygate, and serves chiefly for chimneys, hearths, ovens, and stoves, being a dry porous gritty stone, which bears the heat without breaking, and it is, I suppose, on account of this quality that it has the name given of fire stone.

Purbeck stone is a hard greyish stone, and serves chiefly for paving, coping of walls, and for all such uses where strength is required, as being the most hard and durable stone, after the *Plymouth* marble, we know of; it is found upon the coast of Sussex near the sea side.

Rag stone is that which is commonly used in paving, and is of a blueish kind: but there is a stone called Kentish rags that are very useful in building; they split ve-

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ry easily and yet are very hard; a great quantity of this ftone has been used in Westminster bridge; they are brought down the river Medway from some place near Maidstone.

Alabaster is a clear whitish stone not unlike marble; it is very plenty in some parts of Italy, but there is none to be found in England excepting in some parts of Scotland, where it is said to be very plenty, and much used for

making lime, which is exceeding good.

Free stone is that which comes from Portland, an island near Dorsetshire, and is commonly called Portland stone: this stone is chiefly used in and about London, in all great or small buildings; it is a fine whitish stone without any veins, but very dear; for it costs about ninepence a cubic foot upon the spot, and 16 cubic feet weigh a ton: this stone is very soft when it comes out of the quarry, works very easily and becomes very hard in time; the piers and arches at Westminster bridge are built with it. There is likewise a quarry of street stone at Bath, of which most houses are built there: it has a fine whitish colour, but I am informed that is not durable, and therefore is not so fit for great heavy buildings as the Portland stone.

When the stones are drawn out of quarries and only roughly squared, they are called ashler, but when they are squared and finished, receive other names from the situation they are placed. It may be observed that when stones are laid in the same position as they are found in quarries, that is stat or horizontally, they will make better work than if they are laid any other ways: and they will cement stronger together; this the workmen will not always observe, unless care be taken to

make them do fo.

SECT II.

Of BRICKS.

BRICKS are made here of various kinds and colours; and have various names, as clinkers, famel or fandal, statute bricks, didoron, tetradoron, pentadoron, compass, concave, featheredge, triangular,

cogging, place and flock bricks.

The compass bricks are of a circular form, their use is for steening of walls; the concave or hollow bricks are like common bricks on one side, but on the other they have a cavity, semi-cilindrical, about three quarters of an inch deep, and half an inch broad, so that if two of these bricks are placed with their hollow together, they are like a pipe of an inch and a half bore; they are usually a foot long, $4\frac{1}{2}$ inches broad, and $2\frac{1}{4}$ thick, they are generally laid in clay, and serve instead of leaden or wooden pipes to conduct water, as being much cheaper than any other materials.

Cogging bricks, are mostly used in Sussex, to make their work toothing or indented work under the copeing of walls built of great bricks: they are about ten inches long, 4 broad, and 2 \frac{1}{4} thick. Copeing bricks are about 12 inches square, and 4 thick, stat underneath, and one third above is semi-circular, and the

two ends flat.

Clinkers are nothing else than those common bricks that lie in the middle of the kiln or clamps, where they are so much burnt, that they are as if they were glazed all over; these bricks are always dearer than the rest of the same make, and are chiefly used in foundations, and facing the walls, especially where any water comes near the wall, as being the most durable.

Didoron

Didoron were a fort of bricks used by the antients of a foot and a half long, and a foot broad, but nearly as thin as common tiles. Great bricks are 12 inches long, 6 broad, and three thick; they are generally used in fence walls, made with pilasters or buttresses, and in copeing. This manner of building walls saves great expences, and they will stand as long as if they were every where of the same thickness.

Paving bricks are made of various fizes and forms, from 6, 8, 10, and 12 inches square, and an inch and a quarter more or less thick; those in the form of an hexagon look best; they ought to be of good earth and thoroughly well burnt, otherwise they will moulder away

in a fhort time.

Place bricks differ not in form, but in the manner of making them, being of the common dimensions, viz. 9 inches long, $4^{\frac{1}{2}}$ broad, and $2^{\frac{1}{4}}$ thick, as the statute brick; they weigh nearly five pounds each, though some will weigh $5^{\frac{1}{2}}$; this depends on the quality of the earth they are made of, and on their being well burnt: A cubic yard contains about 460 bricks nearly; which at five pounds, makes two tons and 300 weight per

cubic yard.

There are two ways of burning bricks, in kilns and in clamps; a kiln is a large hole in the form of a reversed frustum of a cone, that is with the lesser base below, built with brick, and a sufficient quantity of earth about it, to keep the heat in as long as is possible; the bricks are not laid close together, but leaving small distances between them, that the heat may pass between; and the fire is made underneath, where an opening is lest for that purpose: This way of burning bricks is esteemed the best, because the figure of the kiln, and the wall about it, are such that all the bricks within are nearly burnt of the same hardness; but where there is a great quantity required, it takes up much time to burn them, for which reason they use clamps in this case; which is nothing else

than a great square or oblong pile of bricks laid so as to leave a small interval between them, for the heat to pass to the external parts; about this pile earth and bricks, which are not sufficiently burnt, are laid to keep the heat in. About London, where they have plenty of cinders, they throw some between each row, which helps to burn them much sooner, and with less fire than is otherwise required.

An ingenious brickmaker told me, that he could burn bricks as well in clamps as in kilns, provided he did it with wood; but the best way of burning bricks for a fortress, is to use both kilns and clamps at the same time, in order to have a sufficient stock of well-burnt bricks for the facings and foundations of the walls and

other buildings.

A bricklayer with his labourer will lay 1000 bricks with ease in a day, when the wall is but brick and a half or two bricks thick, and therefore he may lay more in thick walls; and since a cubic yard contains 460 bricks, he will lay above two cubic yards in a day; and from hence it may be computed how many bricklayers are required to finish a certain piece of work in any given time.

An ingenious man, used much in brickwork, proposed a larger kind of bricks for walls to be built in water, or in a fortification; their size were to be 18 inches long, 9 broad, and 4.5 thick, and he affirmed to have made such bricks in Scotland. But a London brickmaker objected against them; that they could not be managed before they are burnt, as being too heavy, and it would be a difficult matter to burn them quite through: whether this objection is well grounded or not, I shall leave to those who are well versed in this business.

It is certain, that if such bricks could be made, they would be very useful in great works, both upon dry ground and in water, for in the latter case, they would not require so much terrass to lay them in as

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the small ones, which, being very dear, would fave great expences. The Greeks and Romans used bricks of a feet long and a foot broad, in their public buildings, but then they were very thin, that is, about an inch and a half thick, as may be feen in some old buildings, fuch as the old castle at Conterbury; but at present brickmakers disapprove all other fizes but those they are used to, not caring to go out of their own road.

An engineer told me, that he joined several bricks together with firong mortar to compole as it were large stones, with which he formed the angles of the fortress: this must certainly make the walls stronger than by laying the bricks fingly one after another in the

ufual way.

It is my opinion, that bricks might be made of the fize of four common ones joined together, that is 18 inches long, 9 broad, and 2 thick: For as they are no thicker than the usual ones, they would require very little more burning, and feveral of these being cemented together, might serve instead of stone to ftrengthen the wall in those places where it is mostly wanted; I propose this only in such places where no stone is to be had, because it is very certain that, wherever that can be had, it is much better than bricks.

It has been objected, that bricks will not last in falt water; but by confulting Mr. Bratte, the mafter bricklayer of the ordnance, a man of great practice, he told me, that if the bricks were well burnt, fuch as clinkers, and made of the fame clay without any mixture, they would last as long in falt water as any stone whatfoever; as a proof of which he had built the wharfs at Woolwich and Chatham, and besides, in some other places they were used, and without the least appearance of any decay, though a good many years ago.

A friend

A friend of mine told me, that he had feen piers of an harbour at Arles in the fouthern parts of France, entirely built of bricks, and of fuch an age, that the fea has quite left the harbour which is now upon dry land.

There is a kind of bricks called grey stock, which make a very beautiful appearance in buildings, and are chiefly used in and about London, in all front walls, which are exposed to view: The Duke of Norfolk's house in St. James's square is built of a particular fort, the most beautiful that ever were feen, but they are very dear; these bricks are made in the country, and of a composition which I could not learn, it being a kind of mystery known but by a few workmen. Mr. Bratte, our master bricklayer, shewed me some bricks of a pale whitish colour, the finest fort I ever faw; they appeared to me, as if they were made of red clay mixed with chalk, are very hard and found like a hard stone; the insides of the pieces are very smooth, without any cavities: If these bricks were better known, I think they would be preferred to any other fort that I have yet feen.

The best way of making bricks, is to dig the earth before winter, and to let it be exposed to the weather during the winter, which mellows the earth very much, and saves a great deal of labour in preparing it, and the bricks should be made in April, May, June, or July; for after that season the weather grows damp, and then they will not burn so well; and it is pretended by able bricklayers, that bricks should be two years old before they are laid, in order to make good work, and no brickwork should be made after the month of August; because the mortar has not time to harden before the damp weather comes in; by which it peals off, and the works require new pointing the very next summer, as I have

been myfelf an eye-witness to such works.

As bricks are nothing else than artificial stones to supply the want of real ones, there is no doubt but their durableness depends on the goodness of the mate-

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rials, well mixt, prepared, and well burnt; and therefore, an engineer that proposes to make good works, must be very careful in his choice; but the best way to prevent any imposition, is to have the bricks made near the place where the fortress is to be built, by skilful workmen, where the engineer, or those under him, may observe the workmen, so as to perform their work in a proper manner; and the government will have them much cheaper than to buy them by contract, as is the custom.

S E C T. III.

Of LIME.

I ME is made of all kind of stones, that will calcine; that which is made of the hardest stones is the best, and the worst of all is that made of chalk; the way of knowing whether a stone is calcinous, is to take a small piece, the fize of a walnut, and burn it in a common fire, and after it is red hot, to let it cool, and then fling some water on it, and if it smoaks and diffolves, it is a fign that it calcines; but the easiest way of knowing upon the fpot whether a stone will calcine, is to carry a small viol of aqua fortis with you; by letting fall a few drops on the stone, it will boil and dissolve a part of it, if the stone will calcine; but if it lies upon the stone like oil, and does not ferment, you may be certain that it will not calcine,

I have tried a great many forts of stone, first with aqua fortis, and then in the fire, and have found the experiment to answer: I was told that free-stone, such as comes from Portland, would not calcine, but I found the contrary by both experiments; others pretend that flint and a kind of gritty pebble stone make the strongest lime; but all the trials I could make

would

would not calcine them; for which reason, I am of opinion, that they make no lime, and those who pretend they do, have it only from hearsay, without any other proof.

It is my opinion, that all stones that have any metallic particles in them, and those that will vitrify, will never calcine, at least, I always found it so; but lest I should be mistaken, I leave it to the chemists, and those that have an opportunity of making more experi-

ments than I, to decide it.

Different counties in England produce different kinds of lime-stones; in Kent, where there are a great many chalk-pits, they make their lime of chalk, and the greatest part of the lime used in and about London comes from thence, chiefly because of the conveniency to bring it by water, which makes it much cheaper than any other that is brought by land: But this fort is the very worst that can be made; it is true, it may serve very well for whitewashing, and other things in the inside of a building; but as most buildings are upon leases, people are not so nice about the strength and goodness of the work; provided it lasts as long as they want it, it is sufficient.

I have been informed that about eight miles from Portsmouth, is a chalky rock, pretty hard, that makes very good lime, and has been much used in building the fortification of that place: although the Purbeck stone which is not a great way of, and the fragments of Portland stone, make exceeding good lime: I suppose the former lime is used, not because it is better, but cheaper than the other, which is a very bad reason, since all public works, which are of great importance, ought to be made as strong and durable as is possible; for what is saved by cheapness of the materials, is lost by

the short standing of the works.

The best lime in any part of England, is that which is made of the marble, found near about Plymouth, and is very much used in all the country thereabout; the

Romans

Romans and Italians made use of no other lime than that of marble, in all their great and public buildings, it being the very best that can be made, and of consequence, makes the buildings more lasting than

any other.

Most builders in this country do not stand so much upon a good reputation, as to make most money of their works; and sew gentlemen enter into the knowledge of building; so that the works are generally badly executed; provided the outside of walls appears well, it is no marter how the rest is. What spoils the method of making strong and good walls is, that most houses in and about London are built upon leases, so that if they but stand the number of years proposed, the proprietors are satisfied, and give themselves no surther trouble; this causes the workmen to make their work in a slight and expeditious manner.

I am informed, that in most parts of Scotland there are exceeding good lime stones, and in great quantity, in such a manner as to use the same stone for lime as they build with; in some parts they have alabaster, which makes as good lime as marble. In Ireland, especially about Dublin, lime-stones are likewise so plenty as to build with, which makes the best work; because the mortar unites better with the stone, than if

the parts were diffimilar.

An engineer employed in any part of the country, ought to examine all the different stones to be had thereabouts, in order to find that which makes the best lime, and ought not to chuse any because it is the cheapest, which can scarcely be excused in private buildings, but such as will make the best work; and since lime is the very soul of good mansonry, it cannot be too good; but if it should so happen that all the lime in the country is very bad, he should get as much from other parts that is good as to serve for the facings of the wall, for sourceen or sisteen inches deep; the rest may be done with the cheapest sort.

Lime

Lime is burnt in kilns much like those of bricks; and the stones must be broke into pieces the bigness of a sist, and more especially so when the stone is very hard; but when they are soft, such as chalk, it requires not so much precaution: Care must be taken to burn it every where alike, and thoroughly; otherwise, those parts which are not well burnt, will not slaken with the rest, and when the mortar is employed, will dissolve, and disunite the wall wherever there is any of them.

There is likewise lime made of all forts of shells of sea fish, which is esteemed to be exceeding good, because it dries and hardens in a short time, for which reason it is mixt with Dutch terrass, and used in all aquatic works; and, as it is much cheaper than terrass,

it faves great expences.

It must be observed, that those stones taken out of quarries which are damp, make better lime than those found above ground and are dry; it has likewise been found, that the dryest part of rock, and which is exposed to the sun, will make a different lime from that made of the inner part, which is damp and not exposed to the sun: Therefore an able engineer should not only try the outward parts of a rock, or a quarry, but likewise those parts which are not exposed to the sun and weather; otherwise he may possibly reject the best part as useless.

SECT. IV.

Of SAND, TERRASS and POZOLAN.

A LTHOUGH there appears very little difference in fand, yet there is some which being mixt with lime makes much better mortar than others: In common buildings, they always use that which is nearest at hand, and in London they beat the rubbish

of demolished buildings, and use it as sand; but in works of consequence, such as those of a fortress, such a practice ought to be rejected; the best materials should be used in order to make durable work, for which reason greater precautions must be taken; and it is for the sake of those works we intend the following observations.

The best sand for good mortar is that whose grain is not too small, which is clear and free from earthy particles; for the small-grained sand has been found not so good, as being too sine to form a solid body

when mixt with lime.

The manner of knowing whether fand is free from earthy particles, is to take fome and rub it in your hands, and if it makes them dirty, it is a fure fign that it is not pure, but if it be gritty and leaves no dirt behind it is very good. If it should happen that no good fand is to be found near the place where it is wanted, the best way will be to wash as much as is required to make strong mortar, for facing, and pointing arches, and other such like works; that is, you put a good quantity into a tub, and fill it with water, then stir it well with a stick, and let the water run off; pour clean water in again, stir it and let it run out; this being continued till the water is pretty clear, your fand will be clean.

Sand found in rivers is estemed the best, because it is of a pretty coarse grain, and mostly free from mud; others will have it that fand out of the sea or salt water is likewise very good; but as for my part, I would not chuse to use it, where good work is to be made, because salt, if I am not mistaken, is a bad ingredient for mortar; this will be explained hereaster.

It has been found by experience, that fand should be used fresh, and before it has been too much exposed to the air; for it is said, that dry sand never makes good mortar, although mixt with a sufficient quantity of good lime; and therefore when a large quantity is

brought

brought to the place where it is wanted, it should be

covered fo as the fun may not shine upon it.

Instead of sand mixt with lime to make mortar, several other things are used, such as cinders, tiles, scalings of iron out of forges; but these ingredients must be well beat, so as to make a fine powder of them. I made several experiments with these materials, and found when they were well mixt with lime they made excellent mortar; some of which being put into joints of walls in the month of December, the weather being very damp, and others kept in a warm room, made up in small balls, that which was exposed to the air dried as soon, and grew as hard, as the other: Neither could I perceive any difference between the mortars made of these different ingredients, for they grew all equally hard nearly at the same time, although some pretend, that the scalings of iron make the strongest mortar.

I have been told by a gentleman, that he has feen mortar composed of scalings of iron, and common lime, to be used in cisterns, and that it grew so hard that the water could never penetrate it; but it must be observed, that mortar of this kind is worked with very little water, in such a manner as to become like a

strong clay.

There are feveral other kinds of powder used in mortar instead of sand, especially for cisterns and aquatic works; there is a fort which is called pozolana, from the name of the place it comes from, which is in the kingdom of Naples; this powder is of a reddish colour, and when mixt with lime grows presently hard

and remains fo although in water.

Another fort made of a foft rock stone, found near Collen upon the lower part of the Rhine; it is burnt like lime, and afterwards reduced to powder by means of mills; from thence it is brought to Holland in great quantities, where it has acquired the name of Dutch terrass; it is of a greyish colour when it is not mixt, which is very seldom the case; because it is very dear,

and

and absolutely necessary in all aquatic works, and so

they make as much of it as they can.

We have forgot to mention before, that lime should be burnt with coals and never with wood; the reason given for it is, the coals being strongly impregnated with sulphureous particles, which mixing with the lime makes it more glutinous; and it has been found that the mixture of the cinders and the small particles of lime, found in the lime kiln, being reduced to a powder and used instead of sand, compose a mortar as strong for aquatic works as Dutch terrass. The reason of this appears to be owing to the particles of lime being mixt with the cinders and unstakened; when they are mixt with lime they staken and dry up the watery parts of the lime, and leave no more moisture in it than what is sufficient to lay hold on the bricks or stones, and compose as it were one solid body.

I have been informed, that in some parts of England, which is Dorsetsbire, if I am not mistaken, is found a soft stone, much like that of Dutch terrass, and that it might serve sull as well in aquatic works; if this be true, I am surprized that it is not better known, since it would enable us to make these kind of works of our own materials, and much cheaper, than to buy them from the Dutch, who often mix it with other things, to get the more by it. As for my part, I do not doubt, that, if there was a proper enquiry made by such as have it in their power, they might not only find such sort of lime stone as that which the terrass is made of, but likewise the fort which makes plaster of

Paris.

N. B. There is at present such terrals made here, and sold for eighteen pence a bushel, whereas the Dutch costs two shillings, and is not better.

SECT. V.

How to prepare and make MORTAR.

If E manner of making mortar is quite different in different countries, and even in the same country by different builders; the common way in and about London, is, to say the lime stones upon a heap, and cover it with as much sand as is thought requisite for making the mortar; then they sling some water on it, so as the sime may slaken gradually and mix it at the same time, which they continue till the lime is slakened; when this is done, they pass it through a screen the next day, in order to separate it from the small stones, which have not been sufficiently burnt to slaken so soon; after this they mix it and beat it well; and use it immediately without any surther ceremony.

But our engineers use greater precautions; for they mix and beat it every 24 hours for a week together, and then let it lie for a week more, and when they use it, beat and mix it again; by this means it will make good mortar although the lime is but indifferent, provided,

there is not too much fand put into it.

The proportion most commonly used in the mixing of lime and sand is, to a bushel of lime a bushel and a half of sand; that is two of lime and three of sand; this however is no general rule, for some lime is fatter or more glutinous than others, and therefore will bear a greater quantity of sand. The common mortar in and about London has more sand in it than according to the proportion above: for provided there is just lime enough to keep the sand together, the workmen are satisfied: and they make large joints, because this kind of mortar being cheaper than bricks, they get so much more by their work, than if they made the joints smaller; but if they are obliged to make good mortar, they make smaller joints, because the mortar costs them more than bricks.

The French make their mortar in a quite different manner; for they dig a square hole in the ground, a foot or 18 inches deep, and large in proportion to the quantity of lime they intend to flaken; they floor the bottom with boards; then they throw in lime first 6 or 8 inches deep, and pour in as much water as will just cover the lime; which they stir till the lime stones are dissolved; when this is done they make their mortar in a few days after: this is the common practice, but in works of consequence, they cover it with one third of fand and let it lie for a twelve-month. It is pretended that the ancients flakened their lime many years before they used it; and there are some who say that fresh mortar is better than old: but in my opinion the nature of the lime should be consulted; for when lime is very strong, by letting it lie too long it will grow hard and unfit for use, as it happend at Metz, as Mr. Belidor says, where they let it lie a twelve month, in which time it became as hard as stone: but when lime is bad, I take it, the longer it lies the better it becomes.

Two things are to be observed, in order to make good mortar, which are, that no unstackened particles of lime remain, and not putting too much water in it when it is prepared: therefore if lime is kept till every part is slakened it will be sufficient. It must likewise be observed, that burnt lime should not be kept too long before it is slakened, because it evaporates and the air makes it lose its property; but when lime is once slakened and well covered with sand, as likewise under shelter from the sun and rain, it will keep as long as you

please, provided it does not grow too hard.

The water that is used in the slaking of lime, requires likewise to be considered; for if it be dirty and full of mud, such as is gathered in the streets, as they do at London, it will spoil the mortar; it is imagined that all kind of clear fresh water is good; but I believe the softer the water is, the better: some pretend, that salt water out of the sea may be used; but for my part I think

fome-

think it must diminish the goodness of the mortar very much: For it is well known that falt gives way and becomes sluid in damp weather, and therefore in winter, the mortar which is impregnated with falt must necessarily become soft, whereby it loses the property of binding bodies together in bad weather, when it should have most.

Mortar that is to be used directly, which ought never to be done but in cases of great necessity, should be slakened by covering it with sand on a platform, and the water thrown over it little by little, so as to dissolve it gradually, and then passing it through the screen to free it from the small stones not dissolved; this being done, it should be well beat and worked once a day for a week, and let it lie for another, and when it is used, to work is well again; and no water should be used but the first time: but when mortar can be made betimes, it may be made in the manner mentioned above, and let it lie for about six months, which will be sufficient to dissolve all the parts of the lime that is burnt, and the rest which are not burnt will not affect the work; although those that are found may be thrown away.

The mortar made for ceilings is different from that we have been speaking of; it is made of ox or cows hair well mixt and tempered with lime and water, without any sand. The common method of making this mortar is, one bushel of hair to six bushels of lime; the hairs serve to keep the lime or mortar from crack-

ing, and to bind and hold it fast together.

Mortar made of terrass, pozolana, tile dust, or cinders, is mixt and prepared in the same manner as common mortar; only these ingredients are mixt with lime instead of sand in a due proportion, which is about half and half. As this mortar is designed for aquatic buildings, the reader may easily imagine that the lime used in it ought to be the very best that can be had: for which reason, lime made of shells or of marble is what should be had if possible, but in such works which are

fometimes dry and at others wet, instead of terrals. which is very dear, tile dust or cinder dust may be used. and is esteemed to be the best mortar for such work: for it has been found that terrals mortar is not fo good

where the work is exposed to the air.

In fortifications, docks, or piers of harbours, I would lay all the parts of the works under water with terrafs mortar, and the rest of the facings, both within and without, with cinder or tile dust mortar, for about two feet deep; for if this was done, the walls would not require to be pointed and repaired as they commonly do: cellars, and all kinds of arches or vaults, under and above ground should likewise be done with this mortar: and the cinders out of lime kilns mixt with the particles of lime stone, is, in my opinion, still preferable, for the reasons given in section III. As to cisterns, they require terrais mortar as well as all the works which are constantly under water.

The strength or goodness of mortar does not only depend on that of the materials of which it is made, but likewise on the manner of preparing it: for the workmen put generally much water in it to make it liquid. in order to fave labour in mixing it; if this be done. the mortar will never be good for any thing: but if little or ro water is used after it is slakened, and well beat. and mixt till it becomes foft, and this be repeated feveral times till it becomes glutinous, you may depend

upon it, that the mortar is good.

A very able person, who has been employed a great while in the works of fortification, told me, that he wets his mortar very sparingly, but beats it well every day for a week, and then lets it lie for a week or a fortnight before he uses it, and has it well beat over again: this method is undoubtedly very good, and ought to be used in all the works of fortifications, fince they are a great charge to the nation, and therefore whoever has the direction of them ought in a manner to be answerable for their goodness.

A contrary practice is followed by some others, who have the direction of works; for I have seen, after works have been done, the mortar crumble off like sand, and when examined, found the lime in lumps, and not half mixt with sand; what can be expected from such work, I leave the reader to judge. Others pique themselves upon making the work look regular; and will have every course of bricks to be three inches high: and as the bricks are but two inches and a quarter thick, the joints must be three quarters, from whence the goodness of the work may be judged: instead of making the joints so large, I would oblige the bricklayers to make them only a quarter of an inch thick, which is sufficient.

Another observation is to be made, which is, that in all walls that have a flope, the courses of brick ought to be perpendicular to the flope, and not on the fame level as is customary; and this for two reasons; first, all stones being cut fquare cause least waste, and are easier to the workmen; and when bricks are used, the joints are equally thick throughout; whereas, when the courses are on the same level, they raise the bricks on the outfide, fo as to make the flope, which makes them wider there than within; and when the mortar is not very good, the walls require pointing very often. Another inconvenience arises, that the outside of the course is perpendicular to the flope a brick length, and the reft lie horizontally, by which they make an angle or bending, fo that the bricks of the same course can never bind together, and the outfide of the wall is no more than a shell the depth of a brick, separated from the rest of the work.

SECT. VI.

Of PLASTER.

PLASTER is different from common lime, in that it composes a solid body by itself, without mixing either fand or any other ingredient, as is done in lime.

It is made of a bluish soft stone, taken out of quarries, which generally are at the side of a hill, much like the stone of which Dutch terrass is made. This stone is burnt in the same manner as lime, and when cold, beat into a fine powder, or dust; and when it is to be used, about a bushel is put into a tub and water poured in, till it becomes liquid; then it is well stirred with a stick, and used immediately; for in less than a quarter of an hour it becomes hard, and good for nothing; another of its properties is, that it will not bear mixing a second time; as lime will do.

Although plaster is to be found in most countries, yet nobody I know, has given a method to distingush it from lime stone: I am apt to think, that it may possibly be the same sort of stone as that found near Collen, of which the Dutch terrass is made; and if it is not the same sort, it comes very near to it; for it dries very quick, and makes a very hard body: it is said not to remain hard in water, but I never heard that it was tried with mixing it with lime; for which reason, I will

not affirm it to be the same as terrass.

That which is found in a hill near Paris, is esteemed the finest, and brought to England chiefly to make busto's, and to take off medals, as well as all kind of statuary works; but there it is used in flooring, and to line the inside of stone walls, instead of common mortar. But the plaster sound in this country, being of a coarser fort, is chiefly used to make floors for gentlemens houses, and for granaries to keep corn in.

The

The only way to know the stone, is to burn it in a fire, and reduce it to a fine powder; then if it grows hard immediately after it has been mixt with water, you are certain that it is plaster; although the stone is of a blue greyish colour at first, yet it becomes very white by burning, and when mixed with water, it does not fer-

ment or grow hot like lime.

Having thus given the quality and manner of preparing the chief materials used in works of a fortification, in the preceding sections, as far as we possibly could from our own observations, and what we could gather from other authors; to which, if the young engineer will join his own observations with those of his superiors, under whom he is employed, especially to those of able workmen, I do not question, but he will be able, not only to judge whether works are well executed, either in the whole or in parts, but likewise know how to proceed whenever he shall be employed as the chief director over such works, for which reason, we shall proceed to what remains to be said of this subject.

PART

Containing the manner of tracing a Fortress on the Ground, to make an Estimate, and to execute the Works.

SECT I.

Shewing the USEFULNESS and NECESSITY of building FORTRESSES.

HE necessity of building fortresses in all states whatsoever, appears from this innate principle of felf preservation; for a powerful nation has always powerful enemies; fo that by the loss of a battle, the whole country is in danger, if the remainder of the routed army has no place of fafety to retire into, where they may rally and receive fuccours, either from their allies, or new-raifed troops from that part of the country, which the enemy is not yet mafter

It has often happened, that after an army has been defeated, it has received fuch fuccours in a place of fafety, as not only to have been able to fuccour their own country, but likewise drive the victorious army out of the field with lofs. There are many fuch examples to be found, both in antient and modern histories: Whereas, if an enemy gets once the victory in a country that has no forcresses, he is at that instant master of the whole state.

An example of this kind has happened here in England; for had there been some good fortified places, when William the conqueror entered the country, it would not have been lost by gaining of one battle; and had the town of Genoa been fortified in the last war, the Austrians could not have taken it at once, and been masters of the whole state, as they did; in short, were it not for the many fortified places in Flanders the Austrian dominions in that country would have been long

ago loft.

In small states and republics, they are no less necessary than in great kingdoms, in order to resist a powerful enemy, till such time that their allies can come to their assistance. To this it may be objected, that fortissed places in a free state, may be a means to enslave it by some ambitious and powerful man, assisted by a neighbouring prince; but as no such examples are recorded in history, as far as I know, and the contrary is evident, by the states of Holland, who have many fortissed places, and yet have preserved their liberty, since their first separation from the Spaniards, it is evident, that this

objection has no foundation.

Maritime powers, and those who inhabit islands, such as England, Sardinia, Sicily, &c. require no less fortissed places; for as an enemy may invade them by a surprize, and though his naval force be less, yet, when he once gets a footing, he may either conquer or destroy the country. Besides, their trade, on which islanders chiefly depend, would become very precarious, without having some strong place or other to secure their effects in, which otherwise might be surprized and carried off, before an army can arrive to defend them. Many other arguments might be alledged to prove the usefulness of fortissed places, were it not that all the world is convinced of it at present, and therefore it would be needless to say any more about it.

had the rown of Care book forth of his the left was all a se bas som SECT. II. a bloos m.

Of their SITUATIONS.

THE situation of a fortress depends chiefly on the reason for which they are built; for if they are to promote or protect trade, they must be placed near the fea, lakes, navigable rivers, or channels; if they are defigned to guard a pass or inlet into a country, they are placed on hills or high ground, that from thence they may infilade and defend that pass, and so as not to be commanded by any other adjacent hill; or near the passage of a large river; and if they are to secure a country from an invalion, they must be situated in fuch a manner, that the enemy must attack them before he can advance any farther; and in case he should pass by and leave them behind, they may cut off his communication with his own country, whereby his convoys may become precarious and difficult; and therefore must either advance farther or else besiege them.

In islands, the best situations are upon the coasts, and in fuch places, where an enemy may eafily land, and where the garrison has a fafe communication with fome inland town, to receive fuccours and subfishance in case of an attack; or if there are any great rivers, that run into the sea, and where ships may come up into the country, there should always be one or more fortreffes built near them, in fuch places, as may prevent the ships from passing by, without suffering greatly from the cannon placed there, and where the approach is very dangerous.

In an island of no very great extent, whose coast is oban ealy access, in most parts, and where it is impossible to fortify every one; the best situation for a forties is the middle of the island upon a rising ground;

because troops may best be sent from thence to any part, to oppose the landing of an enemy; but this fortress should be pretty large, that, in time of need, the inhabitants of the country may retire into it with their cattle, and other most valuable effects, and help to defend the place, till the enemy is obliged to retire, either for want of provision, or having no hopes to get masters of the place.

But if the island is considerable, it is not sufficient to build fortresses near the most convenient landing places, but there should likewise some be built in the passes, to prevent an enemy from entering farther into the country, in case he should land, notwithstanding the forts on the coast; or at least to stop and protract time, so as the country may rise and come to oppose

him.

In small states, that lie in an open country, which cannot afford the expences of building many fortresses, and are not able to provide them when built with sufficient garrisons and other necessaries for their defence, or those whose chief dependance consists in the protection of their allies; the best way is to fortisy their capital, which, being made spacious, may serve as a retreat to the inhabitants in time of danger, with their wealth and cattle, till the succours of their allies arrive.

If a fortress is built near a river, lake, or sea, it must be considered whether it should stand quite close to the water side, or at some distance, so as the works may not be battered by the ships; whether an enemy may easily land thereabouts, and attack it by land; whether the ships may come close, or the water is shallow; when the water is so deep that ships can come up close to the walls, the parapets must be made high, and those that can be seen from the main top, should be covered above with canvase, planks, or with any thing else in time of siege, to cover the troops behind them.

When

When a fort lies so near the water, that it may be battered from the ships, it is in danger of being soon destroyed by the superiority of their fire; on the contrary, when the water is so shallow, that the ships cannot come near enough to batter in breach; care must be taken that the enemy may not land in their boats. and form it by land; to obstruct which, redoubts or batteries must be built, to resist both in front and in flank; and if they can land any where beyond the reach of cannon, these redoubts or batteries must be fortified all round with a wall and good ditch, that they may not be suprized in the rear; as we did at Cape Breton, where the large battery fronting the entrance of the harbour, was furprized, and the guns turned against the town, by which it was obliged to furrender; this would not have happened, if the precaution mentioned above had been used.

In a place where there is a harbour, some parts or other of the fortress should command it, if possible; for though redoubts and batteries are made to defend its enterance, yet if the enemy finds means to destroy some, and passes by others, the harbour lies open for the ships to come in, without any farther obstacle: and as these desences are at some distance from the fortress, they are always taken either by stratagem or main sorce; as being separate from the garrison, and are not easily relieved. But if part of the fortress commands the harbour, the ships are never secure in it till the place is taken, which is all that can be expected.

It is true, that the entrance should not be neglected; for wherever there is a point of land that commands the approach of an enemy, it should be carefully secured by some work or other; and as it often happens that small rocky islands lie in the entrance, which, when properly fortified, are very advantageous in the defence of it: Nothing conduces so much to the safety of a place, situated near the sea, or navigable river,

as those works which keep the enemy's fleet at a distance; since thereby their main strength is of no use to them; and though they should make a descent in some part or other with a few small pieces, yet these may be easily repulsed by the garrison. As these kinds of situations are the most useful to a trading nation, we have so much the longer dwelt upon the method of securing

them in the best manner possible.

When an old fortress is to be rebuilt, the engineer ought not to rely too much on the capacity of him who had made it first; he should consider whether there is no other fituation thereabouts, that might be better than the former; whether the old works were properly adapted to the nature of the ground; how much expence will be faved by building upon the old foundations; whether it is too big or too little; whether by following partly the old plan, and building the rest in a different manner, it would not be better than to follow it in all its parts; or whether by chusing another situation, it would not be too expensive in respect to the advantage gained thereby; in fhort, he should leifurely, and well confider every minute circumstance, in order to form a true idea of the fituation, the figure of the works, and the confequences resulting therefrom, before he determines his choice.

An engineer, who is truly conscious of the trust reposed in him, ought to be extremely cautious in all his
undertakings, and well consider, that he is, or ought
to be, answerable for all extraordinary and useless expences, which he causes to the nation, either for want
of skill, or inapplication; and if a nation was rightly
sensible of the trust they put upon them, I am persuaded
that they should be very careful, and well examine those
who are desirous to enter into such employments, before they admit them.

An engineer requires much greater skill in arts and sciences, than is generally imagined; for it is not sufficient to know how to draw plans, profiles, and land-

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skips; to understand a few propositions in geometry, or to know how to build a wall or a house; on the contrary, he ought to be well grounded in all the most useful branches of the mathematics, and how to apply them to practice, natural philosophy, and architecture; have a good notion of all kind of handicrast works; and above

all things, to be well versed in mechanics.

As the variety of nature is infinite, fo it is impossible to describe all the different situations, where fortresses should be built; it requires the greatest skill and knowledge to fix upon fuch as may answer best all the different expectations; and as the building and maintaining them is attended with very great expences, when they do not answer the intent for which they are built, they are heavy burthens to a nation, without any confiderable advantage: for which reason an engineer ought feriously to consider what he is to do before he begins fuch an undertaking: It is my humble opinion, that the choice of the fituation, and the making a scheme of a fortress should not be intrusted to any single perfon; on the contrary, the expence of fending five or fix upon the fpot, and in concert making a proper choice of the place and works, would be more than faved in the execution.

S'E CT. III.

OBSERVATIONS relating to the SITUATIONS of PLACES,

IN the former fection we have treated of situations in general, it remains now to observe the particulars which are necessarily to be known, before the scheme or project of a fortress is fixed upon. The first thing to be considered, is to know whether the air is wholesome; for it would not be for the interest of a state, to build a place of that kind without the inhabitants being in a way of increasing, in order that there may

be no occasion of sending often a supply of people; besides, a garrison in such a place, would continually weaken to such a degree, as would make the taking it

very eafy.

This may be known by the colour and strength of those who live there, or near the place; and if it is not inhabited, it may easily be known by the situation; because if it be surrounded by low and marshy ground, the place is certainly unwholesome; on the contrary, if the place is a dry soil, and produces plenty of wood and grass, and there are a great number of birds, or wild animals, it is no less certain, that the situation is wholesome and fruitful.

The next thing to be confidered, is to know whether there is a plenty of fresh and wholesome water. fufficient for men and beafts, for without that, no place ought to be fortified, unless it may be supplied by some spring not far off, and which an enemy cannot cut off in time of a fiege; otherwise, it would be impossible to defend it for any time. It may be obferved, that all fweet waters are not equally wholesome; for it has been found by experience, that very clear and well-tasted water, has occasioned particular diftempers to those that drank it constantly. Besides, as fome waters will cure diffempers, why should there be none of contrary qualities? The air of some places is esteemed unwholesome, when it is rather the water that occasions the diffempers. It has been pretended, that the lightest waters are the best to drink : but Mr. Cotes, in his Hydrostatic lectures, has compared the weights of all the different waters that he could get, even some of the river Ganges, which is esteemed the best in the world, but could not find any sensible difference in their specific gravity; if this be the case, its goodness cannot depend on its lightness, but rather, on some quality imbibed from the soil, through which it runs, which cannot be diffinguished by the taste: Others fay, with some justice, that if water be boiled a good

a good while, and let stand for a time, till it is quite cold, and when no settlement is found at the bottom of the vessel, it will be wholesome; this may be better known, by using the same vessel for some time, and then observing whether any sediments are found; for there may be so little at first, as not to be perceived, yet in length of time may gather so much as to make it appear quite plain.

I have been told by a gentleman of veracity, that very clear and well-tasted water, springing out of a rock in *Ireland*, petrifies every thing on which it falls, in a very short time: Therefore water of that quality can never be wholesome, either for man or cattle.

Water feems to receive its chief quality from the nature of the foil, through which it runs, as we have observed before; as for instance, when it comes out of a rock, or of a gravelly soil, it is clear and cold; that which comes out of chalk, is soft and milky; and that of a marshy soil, brackish; this latter sort is the worst of all.

If the inhabitants, or those who live near the place, are subject to any particular distempers, more than those in others, either the water or the air is unwhole-some; it may easily be known, whether the air is good or bad; for if there is any stagnated marshy water adjacent to the place, the heat of the sun draws up the corrupted particles, which fall in the cool of the night, and infect the air; but if there be no such places near about, the air will be good. It is said, that in bad air, the livers of birds and animals are full of spots; but whether this is so or not, I cannot say.

Next to the water, fuel to make fire is to be considered; it must therefore be enquired, whether there is wood, coals, or turf to be had near at hand, or may be brought to the place at an easy rate, either by land or water: this article is very necessary, especially in northern climates; besides its use in preparing victuals, wood serves for most sorts of handicrast works; in short,

every

every thing that is necessary for the subsistence and conveniency of a garrison must be considered, before the construction of a fortress is undertaken, because the expences which attended such works, are always very great; and consequently, every individual circumstance ought to be examined and carefully considered beforehand.

In the next place, it must be observed, whether there are materials to be found for the building of the place, either upon the spot, or near at hand, so as to be transported at an easy rate; such as timber, stone, or brick, lime and sand, or whether they may be partly had on the spot, and partly brought by water; for if the greatest part is to be transported by land from some distance, the expence will be so excessive, that the utmost importance of the place only can excuse the building it.

If it be a place near the sea, or a navigable river, where a harbour is to be made, it must be carefully considered, on which side the fortress is to be placed, both in respect to the landing of the goods, and to the defence of the harbour, as likewise, where the ships

may come as close to the quay as possible.

In a fortress built to promote and protect trade, it must likewise be considered, what kind of goods are to be found in or near the place, what might be brought by ships from foreign parts, and what might be exported, in exchange for those manufactured there, and where to be carried to market.

It may happen, that in some places, such as islands and some other places, where there are very sew things to be had for exportation, yet if the harbour is convenient for ships to come in, when distressed by weather, or the place may serve as a magazine to bring and deposite European commodities, to be from thence, transported by vessels, to some other market; or else, fresh water is to be found for ships, when no other

place is near at hand, as is St. Helena; fuch fituations

may be fortified, and become very useful.

There are many fituations in inland countries, which we have not taken notice of here, and yet may be advantageous for building large fortified places, because their usefulness depends on too many circumstances to be enumerated; therefore we shall observe in general, never to build a large fortification, excepting near navigable rivers, which may ferve for conveniency of trade, and to be a strong barrier to a state; or to stop a pass, through which an enemy might enter into the country; for where there is no river, he may pass by and leave the place behind him; hills that command any of the works, or hollow roads, through which an enemy may approach, should be avoided; and in general, the ground should be level and free from trees, or any other thing, which may favour an approach under cover, for a mile all round.

SECT. IV.

How to make the PLAN of a FORTRESS.

When a state has resolved to build a fortress, an engineer is to survey the spot of ground, upon which it is to be, very exactly, and to draw the plan of it very distinctly, on a large scale, which must extend at least as far as cannon shot beyond any of the outworks, together with several sections or profiles, so as to express the heights of the most material inequalities of the ground; if there be any river or standing waters near it, their breadth and length must not only be taken and expressed in the plan, but likewise all the soundings, in order to know whether any ships or small craft can come there.

If there be any hills or high grounds, or hollow roads near hand, they must be carefully expressed, both both in the plan and sections; after which the engineer must compose a memorial, containing an exact and distinct account of the nature and situation of the ground; if rocky, hilly, marshy, or even; if there is a river, whether it is navigable or not; or if there be a lake, whether it may be useful for navigation, or to strengthen the works; if there is a good foundation to build upon; whether there are springs or river water to be had for the use of the garrison; and wood, coals, or turf, for suel.

If the materials of which it is to be built, are to be had upon the fpot, or, if at any distance, how they are to be brought by land or water; the nature and quality of the materials; their prices, and that of the work-manship; and above all, whether the works are to be built with stone or bricks, where to be had, whether any quarries are near hand, or proper clay to make bricks, and suel for burning them; where to get the lime and sand, whether the materials are good, or but indifferent; in short, it must contain every thing required for the building of the place, and for its maintenance.

This memorial, together with the plan and profils of the fituation, being laid before the council, which has the direction of fuch works; who ought to fend three or more of the most able engineers to the place, in order to examine every particular, and to observe, whether the plan and memorial are both conformable to the fituation; if not in all particulars, to correct them; and when they are sufficiently acquainted with every thing, to make a plan of the fortess, in conjunction, conformable to their instructions, and the consequence of the place.

For it is my humble opinion, that fuch an undertaking should never be trusted to the judgment of one single person, ever so well qualified, as it is too often the custom; and when they all agree in their opinions, a fair plan is to be made on a scale of 30 sathoms to an

inch

inch at least, with proper profils, in order to lay them before the council, with a new memorial, expressing their reasons for making such works preferable to any other, with references to the plan, and why the fortress is made of that extent.

But in case the engineers should not agree in all the particulars; separate plans must be made by each, and the reasons given in writing, in order to be decided by the council, which of them is to be made use of; all this should be done with the utmost candour, and without any views of interest, or preference in respect to capacity, or any thing else whatsoever, contrary to the true interest of the nation.

In making the plan of a fortress, particular regard must be had to the three following considerations:

it is generally very great in such undertakings; by increasing it without necessity, or the importance of the place requiring, it instead of being an advantage, it becomes a burthen to the nation.

2. The number of troops required to guard and defend it, together with the quantity of artillery and ammunition for a fiege. For if this expence should be equal to, or exceed the revenue or advantage arising from it; it is plain, that, instead of being an advantage, it would be a

disadvantage.

3. The extent or capacity of the place, with respect to the space taken up by the works of sortification. For if it should happen, as we are not without examples, that the town could not contain a sufficient number of troops to defend it, besides the inhabitants, it is evident, that it may be taken with less expence than another of sewer works, provided with the same number of troops; as each work would be capable to make a proper defence; and consequently, a great expence would be thrown away on supersuous works to no manner of purpose.

There

ambi-

There are many other confiderations to be had; as that the works should flank or defend each other in the most direct manner possible: that the communication from the body to the outworks, may be easy and fecure, as well as those from one work to another: that the works are properly adapted to the nature of the fituation; if the ground is low, tenaillous, lunets, or fecond ditch and covert way ought to be made; if level, ravelins and covert way only; if there are any hollow roads leading to it, fome works that flank it in a direct manner; if there are any hills or rifing grounds that command some of the works, little forts or redoubts should be made there, with a secure communication to the fortress; or else traverses are to be made in the works themselves, especially, if they are seen in the rear: If the place is large and of great consequence, horn or crown works are useful to secure the gateways, or a spot of ground which might be advantageous to an enemy: In short, engineers should be sparing in their works, to make no more than what are barely necessary, and whereby visible advantages are gained, both on account of faving expences in the building, and in the maintenance of a garrifon to defend it, and in every thing else necessary for its defence.

When an old place is to be fortified, that has some works standing, the director ought to endeavour to find the reasons which engaged the builder to make these works; which being known, he must consider whether they answer the intent, and if not, how to change, either partly or the whole, so as to answer better, to make use of part of the old works, if not the whole; and never demolish old works to build new ones, without absolute necessity, in order to diminish the expences. I have seen projects for demolishing old works and to build new ones in their stead, which were not so good by much. This will always happen, when an engineer is entrusted with works, that does not understand his business; and those very people, are generally the most

ambitious to shew their own performances, whether

right or wrong.

Situations which are partly fortified by nature, such as when there are any precipices, rocks, or which are partly surrounded with water, are very convenient; for the other part may be fortified at an easy rate, besides the place requires but a small garrison to defend it. When the situation is rocky, care must be taken to make use of the rock for the facings of the works, as much as will agree with the plan, which will save expences; blowing up the highest parts to raise the lower ones; but it must be taken notice, that each work is to be of the same level, or nearly so, every where, and that the inner ones rise gradually above those before them.

When the plan of a fortress is fixed upon, the profils must be determined, and it must be considered, whether the works are to be wholly faced with walls or partly, how much the height of the body is to exceed that of the out-works. Engineers vary very much in their opinions, in respect to the heights of the works; Mr. Vauban made the body of the place 6 or 8 feet higher than the ravelins, and these higher by 6 feet than the glacis: Mr. Coeborn did the fame nearly, but made his capital ditch narrow and deep, whereas the former made it wide and shallow; the latter covers the wall of the body very much, fo that it cannot be battered for above three feet-below the horizon, brings the works closer to each other, and makes their defence shorter; the broad ditch, on the contrary, discovers the wall to the very foundation; but when the ditch is dry, works may be raised in it so as to make a good defence; the passage through it to the breach may be obstructed and disputed for a long while. As for my part, I think a middling width is preferable to a large one; that is, I would never make the capital ditch above 16 fathoms at the falient angle of the bafa tion, when the exterior fide of the polygon is 180 fathoms,

Sect. 4. FORTIFICATION. 133 thoms, and so in proportion to the length of the sides.

The reasons given for making high ramparts, are, that they cover the houses and other buildings better than low ones, and that the enemy may be fired at from all the works in the same front, without incommoding those in the outworks. To this it is objected, that when the works rise gradually one above the other, the enemy may ruin the defences all at once, from the first batteries he makes, and then may advance without having any thing else to fear than the fire of small arms; besides the rampart of the place becomes very high, and, of consequence, increases the expences considerably.

On the contrary, if the works were made nearly all of the same height, the guns placed in the inner works cannot be dismounted till the outer works are taken, excepting by shells; but the chance of dismounting them is so very little, that it may be looked upon as

inconsiderable.

Another material advantage arifing from this method is, that the height of the body of the place is much less than the former, and therefore the expence of building it considerably diminished: As to not being able to fire at the enemy from all the works at once, it is of no consequence; because the outward works will hold as many guns as are required to keep the enemy at a distance, and, as he approaches, these guns may be brought into some others, when it is not safe to keep them longer there.

For my part, I would make the heights of the works fo as to terminate in a right line drawn from the parapet of the body to the extremity of the glacis, because by this means great expences would be faved; the enemy must batter the works one after another, and therefore raise as many batteries as there are works; besides you may at any time fire en barbet from any of the

works you please, or is found most convenient.

K 3

Mr.

Mr. Vauban used to raise his revetements as high as the parapets, excepting at New Brisac, where they are not above 3 or 4 seet above the level of the fields: and to build very strong counterforts behind them; whereas Mr. Coehorn, who was more saving, made them

only even with the level of Bergen-op-zoom.

This method is very good, because it saves great expences in the building, and when the place is besieged, the enemy can batter but a very little part of the wall; it requires more time to make a breach, and less expences to be repaired; whereas when the wall reaches quite up to the top, by battering it as low as can be, the upper part tumbling down all at once, makes a breach in a short time; and the expence of repairing

them is very great.

Some will have the walls to begin from the bottom of the ditch, without making very deep foundations. It is certain, that the burying fo much masonry under ground is of no other advantage than to support the walls above them: And when a foundation can be made firm with piles or other ways, it would fave great expences. This may be done in wet ditches, because the wood being always under water will never perish; but it is not fo in dry ones, unless the bottom is very good, the piling cannot be depended on; besides the foundations in the faces, where the breaches are made, should be as deep as can be, because the enemy's miners will otherwise carry galleries under the wall and blow it up, in less time than the breach can be made by cannon: But in the gorges or counterfearps where no breach can be made, nor any danger apprehended for making mines, it would be extravagant to lay the foundations any deeper than is just necessary to support the walls above them.

SECT. V.

To make the estimate of a FORTRESS.

When the plan of a fortress is drawn with proper profils and elevations, and every thing expressed on paper that can be done, or is necessary; all the angles and lines not given by the construction, must be found by trigonometry, according to the manner of the specimen given in our Elements of mathematics, page 209: The quantity of masonry must be computed in the manner taught, in page 261, as well as the excavation and transportation of the earth, and the expences of making the ramparts, parapets and glacis: then if the prices of the several materials are known in the country where the fortress is to be built; it will be easy to make a proper estimate of the expences that a state will be at, in order to have the work executed.

As it is impossible to determine the prices of the materials, which change in every place, according as they are near or upon the spot, and as the labour is dear or cheap; we shall content ourselves here, to give only the quantity of work of all the material parts; which together with the experience an engineer must have before he is employed in so great an undertaking, and the knowledge of the form used in the country, to represent it to the directors of these kind of works in a proper manner, will be sufficient for our reader to understand what is necessary upon such an occasion.

To compute the QUANTITY of MASONRY.

Plate VI. Fig. 1. We shall suppose, that the fortress is a regular pentagon, with ravelins, covertway K 4 and glacis; that the exterior fide A B is 180 fathoms, the faces AH, BE, to be 50; the perpendicular CD, 30, according to Mr. Vauban's first method. Now because we have found in our Elements, page 211, the flanks to be 27.27 fathoms, and as there are 10; the fum of their lenghts will be 272.7 fathoms, or because, we shall express all the contents by cubic yards, which is the usual method here in England, and each fathom is two yards, the fum of the lengths of all the flanks will be 545.4 yards We have likewise found in the fame page, that the length of the curtain F G, is 76.39 fathoms; and as there are five, the fum of their lengths will be 381.95 fathoms, or 763.9 yards: And fince the faces A H or B E, are 50 fathoms by con-Aruction, the fum of 10 faces will be 500 fathoms, or 1000 yards.

It may be observed, that it is the same thing to multiply each length by the number of square yards contained in the profil, or to multiply the sum of all the lengths, by the square yards contained in the profil; whence by adding the sums of the lengths of the saces 1000, the slanks 545.4, and that of the curtains, 763.9, we shall have 2309.3 yards, for the sum or total of all

the lengths of the body of the place.

Fig. 2. Now if the height of the profil ABCD, be 30 feet, or 10 yards, from the foundation AD to the cordon BC; the rest of the parapet is supposed to be of earth only; then if the wall is of stone, according to our tables, the thickness BC above will be 5 feet, and that AD near the soundation 11. In order to find the area ABCD, we must add the two parallel sides AD and BC, which gives 16 feet, and multiply half the sum 8 by the height AB, 30, which gives 240 square feet; and since 9 square feet make a square yard, if we divide 240 by 9, we shall get 26 \frac{2}{3} square yards for the content of the profil; exclusive of the soundation ADIH, and the counterforts; therefore

if we multiply the total length 2309.3, found above by $26\frac{2}{3}$, we shall get 61581.3 cubic yards for the content of masonry contained in the body of the place, exclusive of the foundation and the counterforts.

If we suppose the foundation A H to be 6 feet deep, and 12 broad, as they are rectangular we need but multiply the base, 12 by the height 6, which gives 72 square feet or 8 square yards for the area of the foundation: and therefore this content multiplied by the total length 2309.3, gives 18474.4 cubic yards for the foundation. In order to find the content of the counterforts, we must consider that their whole heighth H B is 36 feet; the length of the base H K, 8.6 feet according to our tables: and if the diffances from the center of the one to that of the next be 16 feet, their breadth will be 4 feet by what has been faid in the first section: whence multiplying 8.6 by 4, we get 34.4 feet for the area of the base or 3.8 2 square yards; and this multiplied by the number of yards, 12, contained in the height gives 45.8 2 for the content of one of the counterforts: The number of counterforts is found by dividing the total length of works, by the distance between the center of one counterfort to that of the next: and fince the total length has been found to be 2309.3 yards, and the diflance 51; we shall have 433, for the number of counterforts; and as the content of all the counterforts is equal to the product of the content of one multiplied by their number; it follows that 433 multipled by 45.84, gives 19860.2 yards for the fum or total content of all the counterforts. Whence we get for the quantity of masonry of the body of the place

The content of the wall foundation 18474.4. counterforts 19860.2.

Total content 99915.9.

Having found the quantity of masonry contained in the body of the place, the next thing is, to find that contained in the faces of the ravelins, which we shall fuppole 24 feet high, and whose profil is represented by the third figure, the thickness above BC near the cordon is 4 feet 4 inches, and near the foundation of feet 11 inches, the fum of the two parallel sides will be 14 feet, 3 inches, half of which multiplied by the height 24, A B, gives 171 feet, or 19 yards exactly, for the content of the area ABCD of the profil, exclusive of the counterforts and foundation.

Now because the faces of the ravelins, are 51.75 fathoms, according to our Elements, page 215; and ten of them will be 517.5 fathoms, or 1035 yards; this length being multiplied by the area 19 of the profil, gives 19665 cubic yards for the content of masonry of the five ravelins, exclusive of the foundation and counterforts.

Suppose the foundation to be fix feet deep, and II broad, then the product of 11 multiplied by 6, gives 66 feet for the fection of the foundation, or 7 1 square yards; now if this content be multiplied by the total length 1035, we shall have 7590 cubic yards, for the content of the foundation.

The length L A of the counterforts is 7 feet, and the height H B 30, including the foundation; therefore the area of the counterfort K B, will be 210 feet, or 23 + square yards; and if the distance of the center of one counterfort to that of the next be 16 feet, the thickness will be 4 feet, or 1 + yard; whence multiplying 23 1, by 1 3, we shall get 31 cubic yards nearly, for the solid content of one counterfort. If we divide the total length 1035, by the distance 16, we shall get 194 for the number of counterforts contained in the ravelins; and therefore this number 194, multiplied by the content 31 of one, gives 6014 cubic yards, for the total content. Consequently, the quanSect. 5. FORTIFICATION. 139
tity of malonry contained in the faces of the raveling
will be

The content of the	wall foundations counterforts	19665 7590 6014
(33269

It remains now to find the quantity of masonry contained in the counterscarp; suppose the sourth figure to be the profil, which is 16 feet high, from the soundation, 2 feet above, and 5 feet 2 inches near the soundation, according to our tables; the two parallel sides being added, gives 7 feet 2 inches, half that sum multiplied by the height 16 feet, gives 57 \(\frac{1}{3}\) square feet, for

the area, or 6.4 yards nearly.

The length of the counterscap is not found without a good deal of calculation, which we have explained in our *Elements*, pages 214, 215, and 216; to which we refer our reader, and content ourselves by giving the amount as found there, for the length before one front, which is 290 fathoms, or 580 yards; and as there are five fronts, five times this number, gives 2900 yards for the total length; this length being multiplied by the content 6.4 of the profil, gives 18560 cubic yards for the content of the wall, exclusive of the foundation and conterforts.

If the foundation is 5 feet deep, and 6.5 wide; then the product of 5 by 6.5 gives 32.5 square feet, or 3.6 square yards nearly, for the section of the foundation; and this number multiplied by the total length 2900, gives 10440 cubic yards for the total quantity of ma-

fonry in the foundation.

Now because the height of the counterforts is 21 feet, and their length 4; the product of 21 by 4, gives 84 square feet, or 9 \frac{1}{3} square yards for the area of the counterforts; and if we suppose as before, the distance from the center of one to that of the next, to be 12 feet, their thickness will be 3 feet or one yard;

yard; therefore the content of one counterfort will be

9 + cubic yards.

If the total length 2900 yards be divided by 4 yards, their distance, we shall get 725 for the number of counterforts, which being multiplied by the content 9 \(\frac{7}{3} \) of one, gives 6766.6 cubic yards, for the total content of masonry in the counterforts. Hence the total content of the masonry contained in the counterscarp will be

1 (wall	1	8560
Content of the	foundation		0440
	counterforts		6766
		Total 3	5766

Having thus found the quantity of masonry contained in the several parts, according to the plan and profils here given, by adding them together, we shall have the content of the whole, exclusive of bridges, gates, and under-ground works.

	body	99916
Content of th	e ravelins	33329 35766
	counterscarp	35766

Total content 1689517

These computations may also be performed as follows; add the areas of the profil and soundations to that of one counterfort divided by 4, and the sum multiplied by the total length, gives the whole content at once. Thus in the counterscarp, the area of the profil is 6.4 yards, that of the soundation 3.6, and that of the countersort 9 \frac{1}{3}, this last divided by 4, gives 2.3 \frac{1}{3}. Now the sum 12.3 \frac{1}{3} of these three areas multiplied by the total length 2900, gives 35766 cubic yards, for the whole content of the counterscap; which is the same as before: The same thing will be true in regard to the rest of the computations.

Although

Although this is not the exact content of the masonry contained in this fortress, because there are solids in every angle, such as are represented in the sourteenth plate of our *Elements*, which must be considered when the works are measured, as well as the coping stones; yet this mensuration is sufficient for an estimate. There are many engineers that are not so exact in their computation; for how could it be, since sew of them have scarcely the least notion of geometry, without which, it is impossible to compute to an exactness any thing of this kind.

To compute the EXCAVATION of the DITCHES. '

The method of computing the quantity of earth contained in the ditches of the body of the place, and ravelins, is reduced to the finding their area's, and then to multiply the fum by the depth of the ditch, that is, by 16 feet, or 5 \frac{1}{3} yards. But by reason of the irregular figures, they must be divided into parts, in the following manner. From the point B draw B L perpendicular to the counterscarp; from the angle F of the slank F draw F T, perpendicular to the line of defence G E, and from the point D, D V perpendicular to the counterscarp I L produced; then if B K be the capital of the bastion produced, we must find the space I L B D, the triangles G E F, D G H, and the circular sector L B K, in order to get the area of the great ditch before one of the fronts.

The length I L of the counterfearp has been found in our *Elements*, page 214, to be 87.85 fathoms, or 175.7 yards, B L is 40 yards by construction; and in the right angled triangle D V I, we have D I, 25.93 fathoms, or 51.86 yards, by page 215; and the angle D I V, 74 degrees and 35 minutes; by which we find the perpendicular D V to be 50 yards, and the base I V 13.78, by adding I V to I L, we shall have V L, 189.48; and if we add the two parallel sides B L,

DV, we get 90, and half their fum 45, multiplied by VL, 189.48. gives 8526.6 square yards, for the space DVLB, from which we must subtract the triangle DVI, in order to get the space DILB; but the side IV, is 13.78, and the perpendicular DV, 50; half the product of these numbers, gives 344.5 for the area of the triangle DVI, which being subtracted from the content of the area VLBD, leaves 8182 square yards

for the content of the space DILB.

The next thing to be found is the area of the triangle G F E, in which the side F G is 76.39 fathoms, or 152.78 yards, the fide EF, 54.54 yards, and the side EG, 170, 28 yards; having the three sides of a triangle, the fegment E T is found by faying the fum 207.32 of the fides GE, FE, is to their difference 98.24, as the base GE, 170.28 is to the difference 80.6; between the fegments GT, and TE, which being subtracted from the base GE, 170.28, gives 89.68, half of which 44.84, will be the leffer fegment ET; therefore the difference between the squares of EF, 54.54, and ET, 44.84, will be equal to the square of the perpendicular FT; which will be found to be 31 yards. Now because the two triangles GFE, DGH, have the same altitude, the sum of their bases GE, 170.28, DH, 89.74 being multiplied by the perpendicular F T, 31, half the product, gives 4030 yards for the content of the space EFGHD.

It remains now to find the circular sector LBK; the angle LBK in a pentagon, is 108 degrees, and 52 minutes, and the radius BL, 40 yards by construction; whence if we say 7 is to 22, so is the radius BL, 40, to the semi-circumference 125.7 nearly; and again, 108 degrees is to 108 degrees 52 minutes, or 108.86 degrees nearly, as 125.7, is to the arc LK, which is 76 yards; then half the product of this arc, and the radius gives 1520 square yards for the content

of the fector L B K.

Now if we add twice the sum of the space DILB, 8182, and the sector LBK, which is 19404, to the space HGFED, which has been found to be 4030, we shall have 23434 square yards for the great ditch, before one of the fronts.

Lastly, The area of the ravelins ditch is to be found; if from the extremities of the face NQ, we draw Nb, Qn, perpendicular to the opposite counterscarp, an: Then because the width of the ditch is 24 yards by construction; and the face NQ, has been found in our Elements, page 214, to be 103.5; the breadth being multiplied by the length NQ, gives 2484 square yards, for the content of the area NQ nb.

In the right angled triangle N b a, the perpendicular N b is 24 yards, and the base a b has been found in our *Elements*, to be 8.72 yards; and half the product of these two sides, gives 104.64 for the content of this

triangle.

The angle NQR has been found to be 73 degrees, and 30 minutes; whence, if we fay, as 7 is to 22, so is the radius 24 to the semi-circumference 75.4; and 180 degrees is to 106. degrees, 30 minutes, or 106.5 degrees, the measure of the angle nQm, so is 75.4 to to the arc nm, 44.6 yards; and half the product of this arc and the radius, gives 535.2 square yards for the content of the sector nQm.

Now if we add the content of the triangle N ba, 104.64 to that of the rectangle N n, 2484, their fum will be 2588.64; and twice that fum added to that of the sector n Q m, gives 5712.48 square yards for the

content of the ditch before the ravelin.

Therefore if we add the contents of the great ditch 23434 to that of the ravelin, we shall get 29146.48 square yards for the sum, and five times this sum gives 145732.4 square yards for the content of the ditches round the whole fortress.

If

If this content be multiplied by the depth of the ditch 16 feet, or 5 1 yards, we shall get 777239.4 cu-

bic yards for the total content of the ditches.

This is not the content of all the excavations to be made; that of the walls, counterforts, and their foundations must likewise be considered; as there must likewife be room for the workmen to work, which cannot be less than two feet, besides the thickness of the wall, the length and breadth of the counterforts; but the flopes of the walls are not to be taken in here, because we have supposed the ditch to be dug perpendicular.

Therefore if R T be the line terminating Fig. 2. the height of the ditch from the foundation, we must find the thickness of the wall at T; which is done by adding one fifth of the height R M 14 feet, to the thickness BC above 5 feet, which gives 8 feet nearly, to which adding two feet more, according to what has been faid above, gives 10 feet, and this multiplied by the height KR 16 feet, gives 160 feet, or 17.7 square yards. Now the foundation DH being 6 feet deep, and 12 broad, to which adding two feet on each fide, gives 16, and this multiply by 6, gives 96 feet, or 10.7 yards nearly; this added to 17.7, gives 28.4 square yards to the area of the profil; therefore 28.4 multiplied by the total length 2309.3 of the body of the place found before, gives 65584 cubic yards, for the quantity of earth to be removed on account of the wall.

The height of the counterforts KR is 22 feet, including the foundation, the length KH is 8.6 feet to which adding two feet more, gives 10.6; this multiplied by 22, gives 233.2 feet, or 26 yards nearly. Now because the thickness of the counterforts has been made 4 feet, by adding two more on each fide, gives 8 feet, or 2 2 yards, which multiplied by 26, gives 69.3 for the quantity of earth removed on account of one counterfort; and as there are 433 of them, we shall have 30007 cubic yards for the total quantity of

earth.

earth. This quantity, added to that above, gives 955.91 cubic yards for the total quantity to be removed on account of the wall of the body of the place.

Fig. 3. To find the quantity removed in the ravelin, where the height R M is 8, and the thickness B C 4.4 feet; one fifth of 8 is 1.6, which added to 4.4, gives 6, to which adding two feet more, gives 8; this multiplied by 16, gives 128 feet or 14.2 square yards for the section of the excavation.

The foundation has been supposed 6 feet deep, and 11 broad, by adding 4 to 11, gives 15, and this multiplied by 6, gives 10 yards for the foundation; the sum of 14.2 and 10, gives 24.2 square yards, which being multiplied by the total length 1035, gives 25047,

for the content of the excavation of the faces.

The height of the counterforts KR is 22 feet, and their length KH, 7, to which adding two more, gives 9, and the product of 22 multiplied by 9, gives 198 feet, or 22 yards; and fince the thickness of the counterforts is 4 feet, by adding 4 more, gives 8 feet, or 2²/₃ yards, which multiplied by 22, gives 58.6, for the excavation made for one counterfort; and as there are 194 in all, this number multiplied by the content 58.6 of one, gives 11368 for the total excavation made for the counterforts in the ravelin. This added to the former, gives 36415 cubic yards for the total excavation.

Fig. 4. Lastly, It remains to find the excavation made for the counterscarp: The thickness above is 2 feet, to which adding 2 more, gives 4, this multiplied by the height 16, gives 64 feet, or 7 yards nearly. The foundation is 5 feet deep, and 6.5 broad, to which adding 4 more, gives 10.5, and this multiplied by 5, gives 52.5 feet, or 5.8 yards nearly; and the sum of the foundation and the wall is 12.8 yards: and because the total length is 2900 yards, the product of this number multiplied by 12.8, gives 37120 cubic yards, for the content of the excavation.

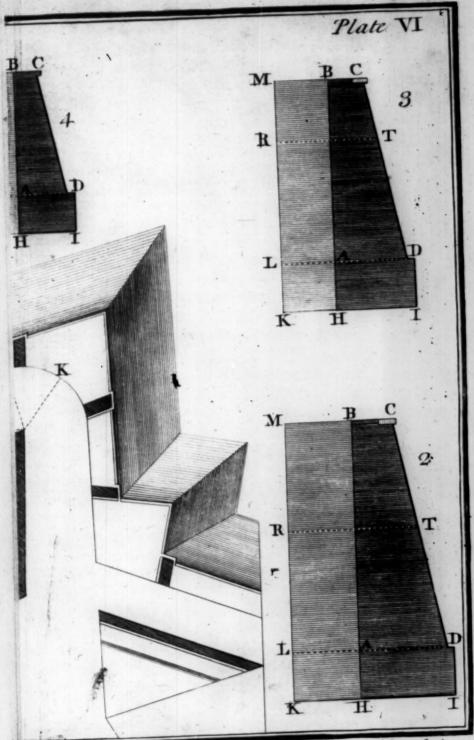
T.

The height of the counterforts is 21 feet, and their length 4, to which adding 2 more, gives 6, the product gives 14 yards for the content; and as they are a yard thick, by adding a yard more, gives 2, and 14 by 2, gives 28 cubic yards for the content of one counterfort; and fince there are 725, the total content of all the counterforts will be 20300. And this added to that of the wall 25047, gives 45347 cubic yards.

Whence the content of the ditches of the town-wall	777239 95591
of the walls of the ravelin of the counterscarp	36415 45347
Total content of the excavation of earth	954592

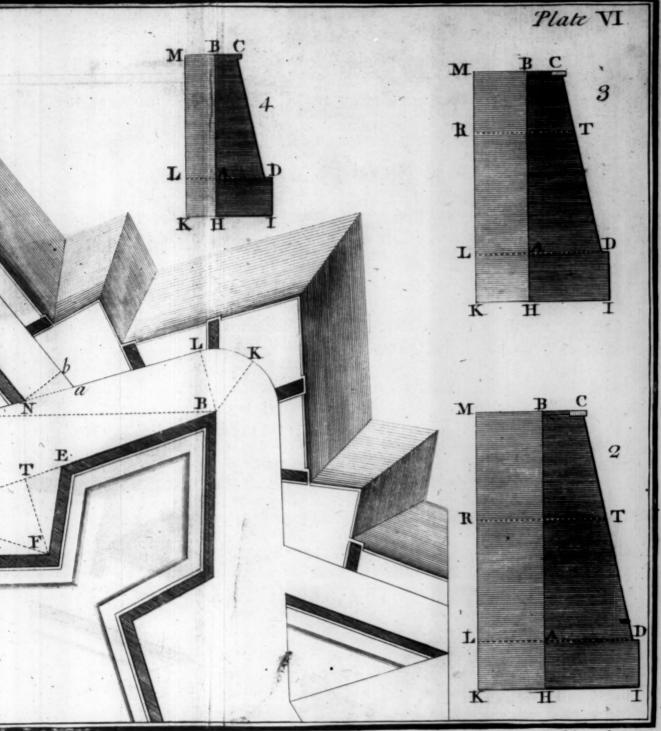
If it is known how many men are required to remove the earth, either from the glacis or the ramparts of the body and ravelin, and how much they remove in a day, the expence for removing the earth may be pretty exactly computed; for there is no fuch thing as to form an exact account, too many accidents happening during the time of the works of this nature, to come to any exactness; for example, if every cubic yard costs fixpence to remove, and make the works compleat, without any other expence either for tools, bridges, and roads; the expence of removing the whole quantity. would amount to 23864 pounds, 16 shillings.

The computation of the quantity of earth has been made upon the supposition that the ground is level; but as this is scarcely ever the case in real practice, marks are left every where to shew the different depths that have been dug, and a proper reduction is made, in order to get the true quantity of earth removed; for which reason the reader must consider what has been here done as the method by which he is to proceed when a fortification is to be executed; and that this is sufficiently exact to make an estimate.

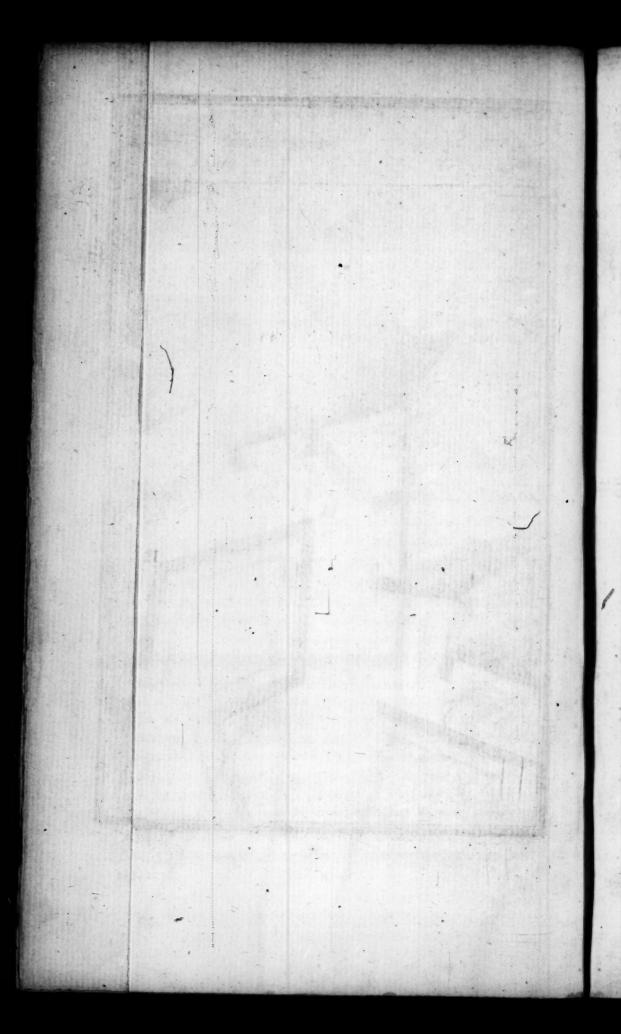


J. Couse Sculp

B



9. Couse Sculp



As to the masonry, it may at all times be known what the stones cost in the quarries, and for the bringing them on the spot; as likewise the expence of cutting them, and to make the walls, when the situation of the fortress is once fixed upon: the same thing will hold good if the place is to be built either entirely or partly with bricks.

But there are many leffer articles, such as the gateways, bridges, cazemats, powder-magazines, storehouses, guard-houses, barracks, &c. which cannot be estimated without a great deal of experience in these kind of works: therefore an engineer must be well acquainted with it before he is able to undertake such a work.

SECT. VI.

To trace the plan of a FORTRESS on the GROUND.

F the ground is uneven, filled with bushes, hedges, ditches, or any other obstacles, which hinder the stations from being seen, it is necessary to trace the exterior fides in a rough manner, in order to clear the ground, and then trace the works over again more exactly. If the fortress lies near a river, the side next to it must be traced first, so as to agree with the proposed plan; or if there are any buildings which are to be inclosed, you begin with that side first, which brings them in their proper fituation: The greatest difficulties happen when the fortress is to be built on a descent of a rock or hill, where the works lie not all on the same level; in such a case, great care must be taken to make proper allowances for raising and falling the works, in order to place them in such a manner that the exterior works be always commanded by the inteinterior ones; it is here where an engineer requires great skill and knowledge to make the different parts answer their true intent.

There are two different instruments commonly used in tracing the works on the ground; which are, the plain table and the theodolite.

The plain table is the most simple, but it is not so exact; for which reason, I would never use it, but in

finall forts, or works of no great confequence.

When a plain table is used, the plan must be drawn on a large scale, at least of 30 fathoms to an inch, which is fastened with sealing wax to the table, so as to lay quite smooth and even; then, by means of a ruler with sights, the angles are laid down on the ground, and the lengths of the lines measured by a chain and rod: But when the theodolite is used, the lines and angles must be found by trigonometry, in the manner given in our Elements of mathematics.

This being done, the angles must be traced on the ground with the instrument, and the lines laid down as before. But to explain the manner of using both these instruments, we shall begin with the plain table, and shew how the body of the place is to be traced, and then how this is to be done with the theodo-

lite.

To trace the PLAN of a FORTRESS with a PLAIN-

Plate VII. Having fastened the plan on the table, in the manner mentioned before; which we shall suppose to be a regular pentagon, of the same dimensions as in the last plate: Suppose the point O to be the center of the place: place the table exactly over the point O, so as the center on the paper is exactly over the center on the ground, lay the edge of the ruler along the radius or capital OA, and turn the table round, till the point A is seen through the sights; place

place a piquet or flake in that direction; keep the table steddy, and turn the ruler about the center O, till it is in the direction O B on the paper, and place a piquet at any distance in that direction; keeping the table in the same direction, lay the ruler on the capital OC, and place a piquet in that direction; and proceed in the fame manner with the capitals OD and OE; this being done, fet off these capitals with a chain in the most exact manner you can, which gives the five points A, B, C, D, E; now to be certain, that these points were rightly determined, the exterior sides A B, A E, &c. must be measured with the chain, and if they are the same length as they should be, you are certain that these points are right: but if the exterior fides are either too short or too long, the capitals must be measured again, till such time that every line on the ground is exactly of the same length as those on the paper.

Having determined the exterior fides, the table is placed at A, and by the help of the ruler turned so as the two exterior sides AB, AE, on the paper coincide with those on the ground; then keeping the table in that position, and laying the ruler along the face AF of the bastion, and a piquet being placed in that direction; then the face AF is measured by the chain, which gives the point F; the table is placed over this point so as the line AF on the paper agrees exactly with the same line on the ground; by keeping the table in that position, and directing the ruler along the flank FG; then a piquet is planted, and the length of the flank

measured, which gives the point G.

After this the table is carried to the point B, and turned so as the exterior sides BC, BA, on the paper agree with the same lines on the ground; keeping the table in that position, the ruler is directed along the sace BL, and a piquet planted in this direction; then by setting off 50 sathoms for the length of the sace, from B to L; the point L is given; to which the L 2

table being carried and turned so as that the face B L upon the paper, agrees with that line, on the ground: then directing the ruler along the flank L H, and planting a piquet in that direction: by setting of 27.27 fathoms for the length of the flank from L to H, which

determines the flank and curtain.

Now to be certain, that this front has been rightly traced, the distance from H to G must be measured, to see whether it is 76.39 fathoms as it should be, and from the points A and B, it must be observed, whether the points B, L, G, and A, F, H, are in a right line; if this is so, the front is rightly traced, and if not, it must be traced over again, till every thing comes out right.

The same operations must be performed at every side of the place, by which the body will be finished for the present, because the rampart and parapet, as well as the thickness of the wall, are determined after-

wards.

If the fortress is either irregular, or there are any buildings in the way, in fuch a manner, that the points A, B, C, D, E, cannot be feen from the center O: The exterior fides A B, B C, C D, D E, must be traced; that is, the table is placed at A, in fuch a manner, as the exterior fide A E on the paper be in the fame direction with A E on the ground; then, by keeping the table in that position, and directing the ruler along the fide AB, in which a piquet is planted, and the lengths of the two fides A E, A B, measured, which gives the points E, A, B; this done, the table is carried to the point B, and placed so as the side B A, on the paper agrees with that line on the ground; then the ruler being directed along the fide B C, and its length being fet off in that direction, gives the point C; in the fame manner is found the fide CD; and if the distance DE is found to be of its proper length, and the angle A E D agrees with that on the paper, the exterior fides have

been rightly determined: after this, the rest is performed in the same manner as before.

If the position of any other line is determined either by buildings or a river, you are to begin with that line and find by its means the exterior side next to it, and from thence you proceed as before: Thus if the direction of the line C D is given, on account of a river, so as to bring the greatest part of it into the great ditch; the table is placed at C, and directed so as the line C D on the paper agrees with that line on the ground; then keeping the table in that position, and directing the ruler along the exterior sides C D and C B; the rest is finished as before.

When an old place is to be fortified, it often happens, that the fituation of one of the curtains is determined, suppose GH; then the table is placed at G, and H, in order to find the flanks GF, HL; and then at L and F to find the faces LB, FA, which gives the exterior side AB; this being done, the rest of the work is performed as before.

To trace the PLAN of a FORTRESS on the GROUND with a THEODOLITE.

When the fortress is regular, the theodolite is placed in the center O, and levelled by means of the cross levels and skrews; fix the index to 360 degrees on the limb; turn the whole instrument round till the north end of the needle hangs over the flower de luce, or 360 degrees in the box; there fix the limb of the instrument by means of a screw underneath, then discharge the index, and turn it about till the vertical hair in the telescope cuts the station A placed any where in the direction O A; then adding the degrees on the limb, which we suppose to be a certain number of degrees exactly, without any fraction, to the number of degrees of the angle AOB, and turn the index fo as to cut exactly the same number of degrees on the L 4 limbs; limb; this done, place a station in the direction OB; adding again, the number of degrees of the angle BOC, to those on the limb, and turn the index round, till it cuts the faid number, by placing a station in the direction OC, and proceed in the same manner all

round, till the whole is finished.

We prefer this practice to any other, because the needle cuts always the same number of degrees nearly, as the index does on the limb; but it may be done thus, after having levelled the instrument, and fixed the index to 360 degrees, you turn the instrument round till the vertical hair cuts any station placed in the direction O A; then the limb is made fast by means of a skrew, and the index discharged, and turned about till it cuts the same number of degrees as the angle AOB at the center, which is here 72 degrees, then placing a station any where in the direction O B, and turning the index about till it cuts as many degrees, as are contained in the angle AOC, which is here 144; by placing a station in the direction OC, the index is turned round till it cuts the angle AOD, 216 degrees on the limb, and so on to the rest; this done and a station placed in OD; then, the index being turned round till the vertical hair in the telescope cuts the first station A; if the index cuts exactly 360 degrees on the limb the angles are rightly laid down, and this it will always do, if the instrument has not been moved.

The angles at the center being laid down very, accurately, the capitals O A, OB, &c. must be measured with the fame care; and to prove the work, the exterior sides AB, BC, &c. must also be measured, and if they answer their dimensions, every thing is right. But if the fortification is irregular, or the points A, B, C, D, E, cannot be feen from the center O; the theodolite must be placed at any one angle as A, which we suppose to be determined by the situation; after the instrument is levelled, and the index placed on 360 degrees,



degrees, the whole instrument is turned round till the north end of the needle points likewise at 360 degrees; the limb is fastened, with the skrew and the index discharged, which being turned, so as the telescope cuts the station in the direction A E, which is supposed to be given; then observing the number of degrees which the angle made by A E, with due fouth and north, suppose 5 degrees, which being subtracting from the angle E A B, of the polygon 108 degrees, then turning the index round till it cuts 103 degrees on the limb, which is the difference between 5 and 108; then placing a station in the direction A B, and fetting off from A to B, 180 fathoms for the length of the exterior fide AB: Now the theodolite being placed at B, and the index fixed to the limb, the whole inftrument is turned, fo as the station at A may be seen through the telescope; then the limb is fastened, and the index discharged, after having observed the number of degrees it points at, to which adding the number of degrees contained in the angle ABC, and if the fum exceeds 360 degrees, fubtract 360 from it, and turn the index round, till it points at the given number of degrees, and looking through the telescope, the station C is placed in that direction: the exterior fide BC being fet off on the ground, gives the point C; from whence proceed in the fame manner as before, till you come to the point E; and when the instrument is brought to the first station A, and the angle EAB is found the same as before, the operation is right.

It may be observed, that by laying thus down the angles from the meridian, passing through the point A, the needle will always point at the fame number of degrees nearly in the box as the index on the limb. which being carefully observed at every station, will shew whether any error has been committed, either by accident or mistake; and if there be any found you must return to the former station to correct it, before

you

you proceed farther; by which you fave the trouble of going over the work again, for a mistake made perhaps at the beginning. Most engineers content themfelves, by laying down fimply, the angles of the poly-

gon without any meridian.

As all the angles and lines of a plan must be found by trigonometry, when it is to be traced on the ground with a theodolite, you place the instrument at A, and fet off the angle BAF, and the length of the face AF, and then at F, to make the angle AFG of the shoulder, and when the length of the flank F G is measured, the instrument is placed at the point B, and proceed in the same manner, to find the points L and H: then if the points B, L, G, are in the same right line as well as the points A, F, H, and the length of the curtain GH comes out right, you are certain, that no miftake has been made: The fame operations are performed with regard to any other front, by which the body of

the place is traced on the ground.

The next thing in hand, is to trace the counterfcarp of the great ditch; which is done in this manner; make the angle MDN, equal to 74 degrees, 35 minutes, according to what is faid in our Elements, page 214; and fet off from D to N twenty fathoms, for the width of the ditch, trace a line in the direction N R, perform the fame operation before the face E R, and you will have the strait part of the counterscarp; the round parts before the bastions are determined by placing piquets at certain distances from each other, fo as to be 20 fathoms diffant from the faliant angles of the bastions; or if the ditch is not so wide, and that the chain may reach cross, fasten one end of it to the piquet at D, and at the other end a loose piquet, so as to reach the point N; then by turning the chain round the piquet at D, so as to keep it always strait, with the point of the other piquet you may trace the round part on the ground.

To trace the raveling, through the middle of the exterior fide DE, mark a line ST, at right angles to it, in which fet off 50 fathoms, for the length of the capital of the ravelin, from the reentring angle S of the counterscarp to the point T; from the point T, trace two lines to the counterfcarp, which when produced, shall meet the opposite faces of the bastion in a point X, within three fathoms, from the shoulder M. As to the counterscarp of the ravelins ditch, it is found by erecting perpendiculars at the extremities of the faces, each of 12 fathoms, for the width of the ditch: The round part is found as before.

To trace the COVERT WAY and GLACIS on the GROUND.

From the reentring angle a of the counterscarp, fet off 20 fathoms for the semi-gorges a b, a c, of the place of arms; fasten two chains or chords to two piquets placed at b and c, each of them of 25 fathoms long; which being stretched, and so as to meet at d, place a piquet there, and trace the faces b d, c d. If two points are marked with piquets along each fide of the counterfearp, and at 6 fathoms from it, then the lines traced in these directions will determine the covert-way: and fetting off two perpendiculars to the fides of the covert-way, and at 20 fathoms from them, the lines traced through their extremities will determine the breadth of the glacis. The traverses are eafily traced on the ground, from their construction on the paper.

This is the most accurate way of tracing the plan of a fortress on the ground; and it may be observed in general, that all works of what kind soever of this nature, are always to be traced, by the help of the lines and angles, either given by construction, or found by

trigonometry.

For instance, to trace a horn or crown-work, on the ground; the angle which their branches make, either with the counterscarp or the faces of the bastion, must be found as well as the length of the branches; these being once known and traced, the rest may be performed in the same manner as in the body of the place.

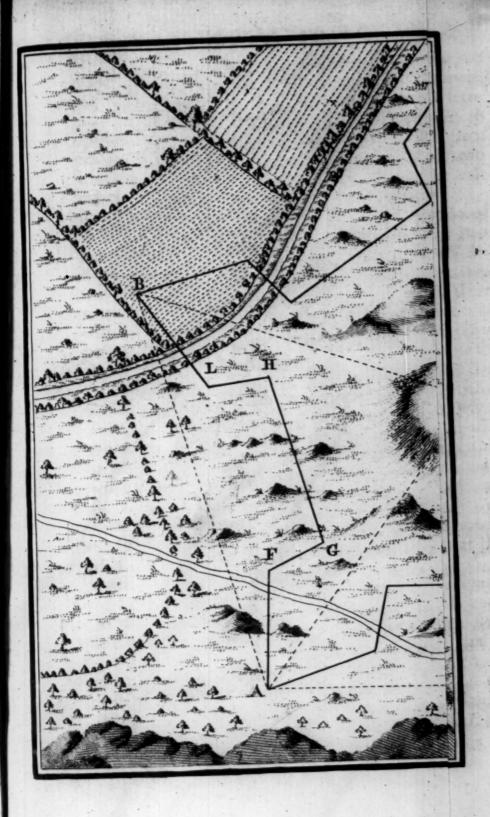
The manner of tracing lunets, tenaillons, countergards, and all such works, differs so little from what has been said before, that it requires no farther expla-

nation.

SECT. VII.

The Method of building a FORTRESS.

A FTER having traced the principal or magistral I line of the works, the ground must be levelled round the body of the place, in order to choose a mean between the different raisings and fallings of the ground for the level of the place, which ought to be fuch that the earth of the higher parts may nearly fill up the cavities of the lower, and the center of the place must be marked, and is generally about fix feet higher than the above mentioned level, in order to get a proper descent for the running of the water into the ditch; this being done, a trench is dug all round for the foundation of the body-wall; but care must be taken, to throw as much earth out of the trench and ditch, towards the center of the place, as will make the rampart and parapet; this may be done nearly by computing that part of the profil above the level ground, and cutting a trench of an equal fection; it must likewife be confidered, how much earth will nearly be dug within the place, for cellars, conducts, faly-ports and cazemats. For the removing the earth out of ditches and underground-works, in such a manner, as just to make

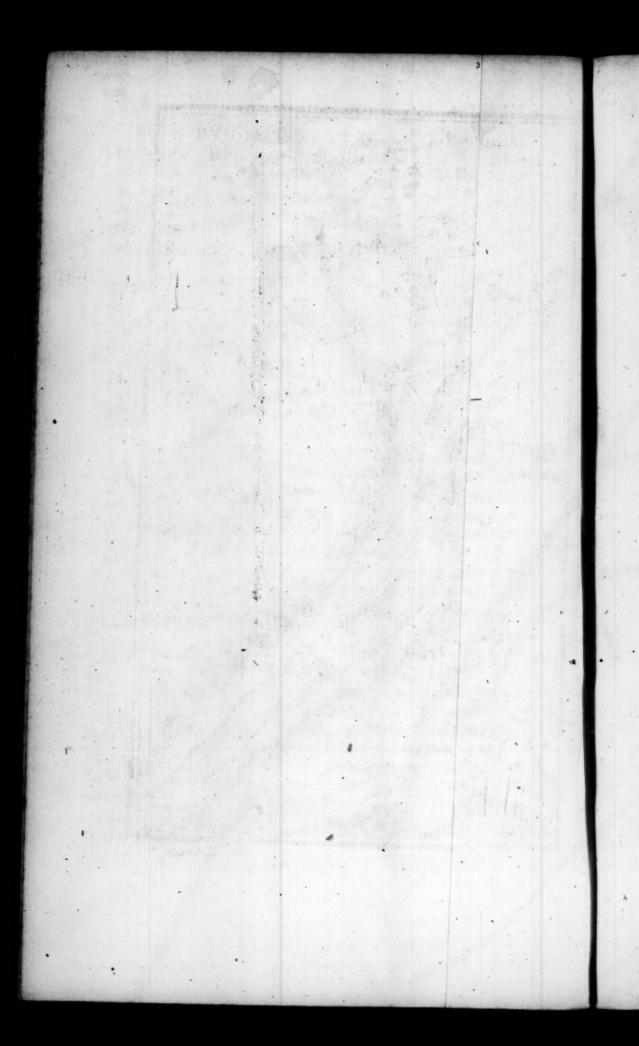




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J. Cowe Sculp .



make the rampart and parapet, and the rest for the glacis, is one of the most difficult tasks that can happen; since it requires great skill to do it so as not to have more than is wanted to compleat the work, and to prevent the moving of it over again from one place where it was thought necessary, to another, which, in my opinion, is hardly possible, and therefore the least removes will be the best.

That part of the trench made for the foundation of any work towards the rampart, ought to be cut into steps, as may be seen in the eighth profil, Plate VIII. and as near the wall as can be, without any inconveniency; because, when the rampart is compleated, there will be only the earth which has been dug, that will press against the wall; whereby its resistance becomes fo much the stronger. In my opinion, the rampart should not be made till such time the masonry is settled and dry, which requires at least a twelve month. unless there is an absolute necessity for it; for when the damp earth is rammed against a wet wall, it will require a great while before it dries, and perhaps this will not happen at all, unless the mortar be very good; for which reason, I would mix cinders instead of fand with the lime, and lay this mortar about a foot and a half deep on the fide of the wall next to the rampart; this will fooner dry, and prevent the moistness of the earth from penetrating into the masonry.

To prevent the pressure of the earth against the wall as much as is possible, branches of all kind of wood are stuck into the earth, by horizontal layers, with the sharp end as deep into the unmoved earth, and as firm as can be, and a bed of earth well rammed, of half a foot deep, in the manner represented in the eighth profil; when this is done, the wall has time to settle well, and becomes quite hard before it suffers any

pressure.

Of the Foundations and the manner of laying them.

Plate VIII. As the foundations of all buildings in general, are of the greatest importance, in respect to the strength and duration of the work; we shall enter into all the most material particulars, which may happen in different soils, in order to execute works with all the security possible; because many great buildings have been rent into pieces, and some fallen down, for want of having taken proper care in laying the soundation; and for a futher explanation we shall join here plans and profils, adapted to the most material situations that can be found.

First, It is necessary to examine very carefully the nature of the soil, upon which the soundations are to be built; for doing this, proper augures are used to bore holes in several places 10, 12 to 15 seet deep, in order to discover the nature of the soil, and its hardness; or, if it is made of several layers or stratas, which is commonly the case, the difference of their nature and goodness; this is known by their colour or the difficulty

of piercing through them.

If the soil be of a good consistence, for a certain depth, without any water or soft ground, and this holds so all round the soundation, there need no other precaution be taken, than to lay the soundation sour, sive, or six feet deep; only observing to enlarge its breadth, in proportion to the height of the walls to be built upon them: Since the higher the wall is the more weight the soundation must support: Although this is self-evident, yet engineers do not seem to mind it, because they make commonly the base of the wall in proportion to the depth of the foundation, and not to the height of the wall.

If the foil be a hard gravel for about 10 or 12 feet deep, the foundation may be built upon it, without any danger of its finking; or if the foil be a stiff clay,

it will likewise be good; the first and second figures represent the profil and plan of such a foundation; where there are two or three courses of large stones to be put at the bottom; and the foundation projects by two or three seet before, divided into as many retreats, but not above a foot behind; because there is no danger of the wall falling backwards: this is the custom, but as for my part, I think there is no occasion for any projection at all backwards; since the counterforts are sufficient to support the wall, and this projection might be of greater advantage before, if added to those already mentioned.

If the foil be not very firm or hard to a fufficient depth, or when some parts are softer than others; it will be necessary to lay a grate of timber first crossways, and then long-ways; or some lay them first long-ways, and then cross-ways, which seems to be best, and well bolted together with wooden trunnels, as is represented in the third and sourth sigures: Sometimes, these grates are boarded over with three inch planks, as is marked in the profil; at others large stones are laid between the timbers of the grate, and laid even with them, upon which the foundation is afterwards raised.

Some engineers choose to raise the fore part of the grate of about a twenty sourth part of its breadth, in order to prevent the wall from being overset by the pressure of the earth, as it has sometimes happened: this precaution seems to me to be very necessary, especially when the rampart is pretty high; and the courses of stone in the soundation should have the same inclination, excepting the last, or the base of the wall ought to be level, if those of the wall are so. I am sensible, that some engineers ridicule this practice, and say, that all beds of stone or brick should be exactly in a level; but Mr. Coeborn, who knew more of this matter than most, if not all of our modern engineers, has not only laid his soundations in this manner, but like-

wife the walls quite up to the top. This is confirmed by L'Abbé Dedier, in his Perfett French Engineer, where he fays, that in repairing the works at Manbeim, which were built under the direction of Mr. Coehorn, they found that the courses of masonry were perpendicular to the outward flope, whose base is one fixth part of the height, and the walls were only about three feet thick above, without any counterforts. the case, and the walls being strong enough to resist the pressure of the earth, this manner of laying bricks or stones has greatly the advantage over that commonly used.

If the foil be fand, and of no hard confistence, the grating the foundation is absolutely necessary; or if the foil be a foft loom or common earth, it is also neceffary to take this precaution; and in general, when the foil is doubtful, though not absolutely bad, a grating fuch as this cannot but be very useful in preventing the walls from finking: and I must repeat it again, when the wall or rampart is very high, particular care should be taken to secure the foundation in the best manner possible; for it is better to do this, though fomewhat more expensive, than to run the chance of making bad work at an easier rate, which might prove

more burthensome at the end.

It is necessary to observe, that when there is any timber under the foundation, the first course of stones should be made without mortar, because its corrosiveness destroys the wood; and in general, where any beams or timbers are laid into the masonry, instead of mortar, stiff clay is used round it; and some carpenters make thin cases of wood round the parts which enter into the wall.

When the foundations are so very bad, that the grate of timber mentioned before is not fufficient, but is hard after a certain depth; upon fuch an occasion, it is proper to drive piles, and then lay a grate over them, fuch as is represented by the fifth and fixth figure; thefe

these piles are to be placed exactly under the crossings of the timbers, to which they are fastened with trunnels, and are to be drove into the ground as far as

they will go.

As this method of laying foundations happens most frequently in the works of a fortress, and is very expensive, care must be taken not to make any more than what is necessary. In order to find the proper length of the piles, one or two are drove as deep as they will go, and then cut a certain number of the same length, and when these are drove, and the depth of the foundation remains the same, more are cut of the same length; but if the foundation changes, the rest must be made accordingly. By this method a good deal of timber may be saved; whereas, if the piles are all cut at once, some will happen to be too long, and perhaps some too short, which wastes a great deal of timber to no manner of purpose.

Some engineers drive piles into every corner of the squares formed by the timbers, and none under the frame, as is represented here; but this method must appear to every judicious reader, not so good as the former; because the frame is supported by nothing but the earth, which, being but soft, must give way to the great weight of the wall pressing upon the frame.

Others drive not only piles under the grate, as we have faid above, but likewise two in every square, that is, in the opposite angles; but it seems to me, not worth while to make such expensive work without an absolute necessity, and when no other method is

practicable.

Besides the piles under the grating, others are to be drove at the outside next to the ditch, as is represented in the plan by the letter a; their number is uncertain, and ought to be regulated by the goodness or badness of the foundation. In both soundations, represented by the third and fifth profils, the outside timber next to the ditch ought to be cut in such a manner that the M

wall may rest upon part of it, and the other part prevent it from sliding into the ditch, or else a smaller timber should be fastened with bolts upon the larger. Mr. Belidor gives an example of a wall sliding in the ditch, at Bergue St. Vinoc, in Flanders, which was the face of a ravelin; the same thing happened some years ago, at our wharf here, at Woolwich, for the middle part of it, slid sive or six feet into the Thames, because the soundation was only clay rammed even with the bed of the river, and which would have been sufficient, had the precaution above-mentioned been staken.

We have mentioned before that sometimes planks are used to cover the grating, and sometimes not; where there is plenty of stones, these planks may be saved; but in walls made of brick they are absolutely necessary; for they being but of a small size, those which rest upon the timber will not be able to sustain those which are between them.

If the foundation is either all rock, or only partly so; the bed of the wall is to be sunk about 6 inches or something more into it, in the manner represented by the seventh sigure, to prevent the wall from sliding, which otherwise might happen, because masonry seldom binds so well with the rock as to make it firm and durable. When the bed is made, care must be taken to sweep it very clean, in order that no rubbish or dust remain in it, and after this, it must be wet as the wall is made; by doing so, the mortar will enter better into the pores and small cavities, the masonry will likewise bind with the rock in a more easy manner, and form in time but one continued solid stone.

Afthough rock is the strongest foundation that can be built upon, nevertheless, engineers look upon it as one of the most difficult pieces of work to be met with; their reason for thinking so is, that they are seldom level, but raise and fall continually, by which the work changes its profil at every small distance, and to raise the foundation to a proper level, and bind the masonry to the rock in a strong and firm manner,

meets with the greatest difficulty.

The fecurest manner of proceeding in such a case, is, to clear the rock, as well as can be, from all dust and rubbish, in the manner observed before, and to sink from four to six inches into it; then raise the lower parts with good masonry made of very thin but strong mortar, so as to be in the same level with the higher ones. This work must be left some time to dry and settle, otherwise, that part of the wall which stands upon the made foundation will sink and break off from the parts which stand upon the rock.

Sometimes the rock will rife at one end nearly as high as the wall itself; in this case, the work must be raised to a level, of about six feet from the bottom, and then left to dry and settle for some time; after that, it may be raised to the same height again till such time as the whole wall is sinished; and to prevent the workmen from standing still, several parts may be undertaken at

the same time and carried on alternately.

Sometimes it happens, that the rock rifes gradually behind, nearly as high as the wall, or, which is the fame, that a wall is to be built against the rock; in this case, the rock must be well cleared from all dirt and rubbish, and if it is too smooth, it must be pickt, or small cavities made in it, that the mortar may lay hold of, and bind it with the masonry; and the work must be carried on gradually and slowly, otherwise the masonry will naturally sink and tear off from the rock.

Mr. Belidor proposes a method for building walls in this case, which, he says, has often been practised by some French engineers with good success; that is, instead of using common mortar and stone in the usual manner, they prepare what is called stone-mortar; which is made of thin but strong mortar, mixt with stones, about the size of a wallnut, a little more or less;

M 2

then they set a kind of coffer without a bottom, cut underneath, so as to agree nearly with the unevenness of the rock; then this coffer is filled with mortar, and let stand till it is dry and pretty hard; then they take the coffer away, in order to place it elsewhere. The reader may easily perceive, that the surface of this mortar is laid smooth and level, and that, when it is well settled, it will stick much better to the rock than any other kind of work whatsoever; these kinds of walls become in time as hard as stone itself, as appears by the remains of such as have been found here, in France, and in Germany.

In some parts of Scotland, in Ireland, at Gibraltar, and Mahon, the rocks are generally of lime stone; in such a case, no better work can be made, than to mix the stones of the same rock with the lime; this will, by the likeness of the parts, form a work that will join to the rock, and in time become as one continued

ftone. .

It happens fometimes that under a bed of gravel, clay, or any other hard confistence, there is a fost watry soil or sand, to a great depth; where it would be dangerous to drive piles, on account of the sources or springs, which are generally under these places, which, when they get once a vent or opening, fill the trench made for the soundation in a short time full of water, in such a manner, as there is no possibility to build there. When this happens, a gutter must be made to lead the water out of the trench into some well made for that purpose, if none is sound near enough, and engines set to work to draw the water out of it into some lower place or ditch.

It may happen, that the water comes so fast into the trench, as not to be drawn off; in both cases, a strong grate of timber must be made, and planked over, which being laid over the soundation, and fast-ened in such a manner, as not to shift its place, then the masonry is built upon it, by which it will sink gra-

dually,

dually, till it comes to the ground, and when the foundation is raised above the water, it is left dry and settle before the wall is continued.

I have been affured by people of veracity, and judges of these works, that many such instances happen in Russia, as well as in Flanders, and yet when the walls are finished, they stand nevertheless as sirm as if they were built upon a strong foundation; it is certain, that these walls will sink, but then the business is to make the whole together without clinks or breakings; which can no otherwise be done, than with very good mate-

rials, and great care and industry.

Notwithstanding that no water appears above ground, and that there is only a hard crust of five or fix feet deep over a swampy soil, yet it is necessary to lay a strong large grate under the foundation; by taking care to sink the trench as little as can be done, for the safety of the work; and the foundation must be carried all round alike by horizontal courses, and no new one begun before the last be quite sinished, so that if the ground underneath gives way, it may be pressed alike every where, and sink together.

This method of carrying on the foundation alike all round the work, should be observed every where, excepting on rocks, or such a hard substance as cannot give way, where it may be done by parts one after another; only observing to join them well together, and by steps, that no two joints may be over one an-

ther.

There are some situations, which, besides being swampy, the trench dug for the soundation sills in a short time with water; the method used upon these occasions, is, to open only as much of it as can be made in a day, and the stones are laid, without any other precaution, on the ground, and the work is carried on as fast as possible, till the wall is above the height to which the water rises; but this soundation must be made very broad and by retreats; and the stones laid

M 3

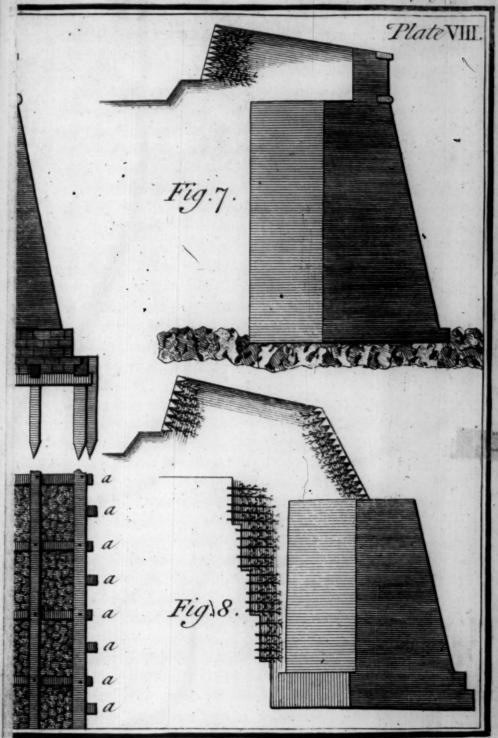
in terrals mortar, that it may foon grow hard; when this is done all round, and the work settled, the rest is built in the usual manner.

These kind of foundations are very common in Flanders, and Mr. Vauban was very much puzzled at first how to proceed, till some workmen of the country, who had been used to them, put him in a method of it: I have seen the same at Douay, where they dug a trench of about 40 yards, and three seet deep; and as fast as it was opened the masons worked at the foundation, which was raised six feet high; though the next day half of it was under water, yet the work stood as well as if it had been built upon a solid foundation.

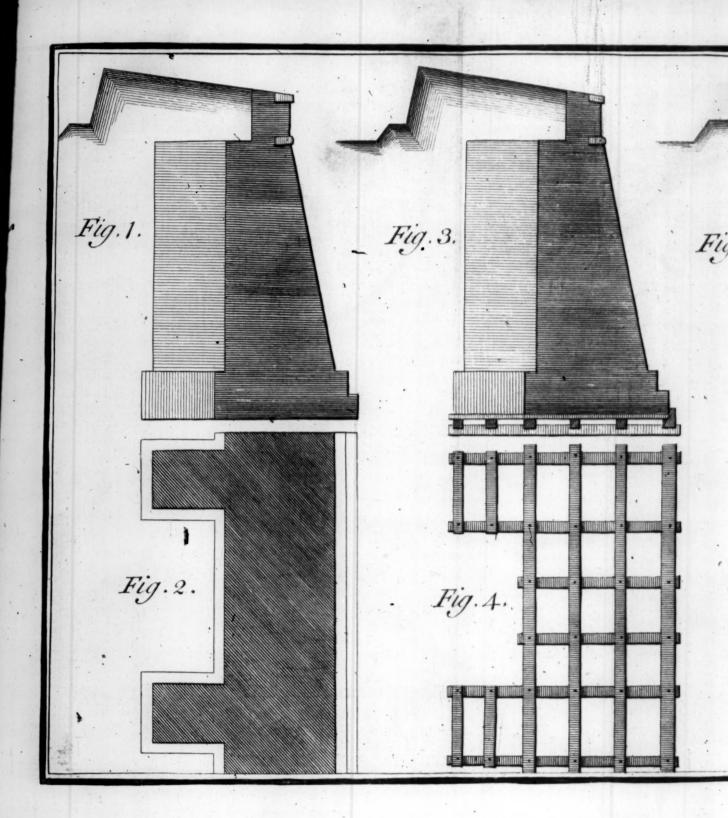
As the different fituations and foils require different precautions, it is impossible to give particular methods for every one; the most secure and probable, by which an engineer may succeed, is, to consult the workmen, who either live upon the fpot, or near it, and who have been employed in fuch foundations; for they generally know best, what method will most likely succeed; by confulting feveral upon the fame subject, if they differ in their opinion, which is often the case; it is the engineers business to judge what is best to be done, and from his own experience, joined to that of the workmen, deduce the method, by which he is to carry on his work: But, notwithstanding all human precautions that can be taken, yet accidents will happen, which are to be repaired as foon as possible, and whereby the engineer will learn how to avoid them afterwards, in the remainder of his works.

We have endeavoured to give here most of the several cases, which commonly happen, in all foundations made upon the land; and which, if studied with care, I do not doubt, but an engineer with a moderate share of practice and knowledge will be enabled to perform such works: But the manner of laying the foundations in water for bridges, sluices, moles, and piers for har-

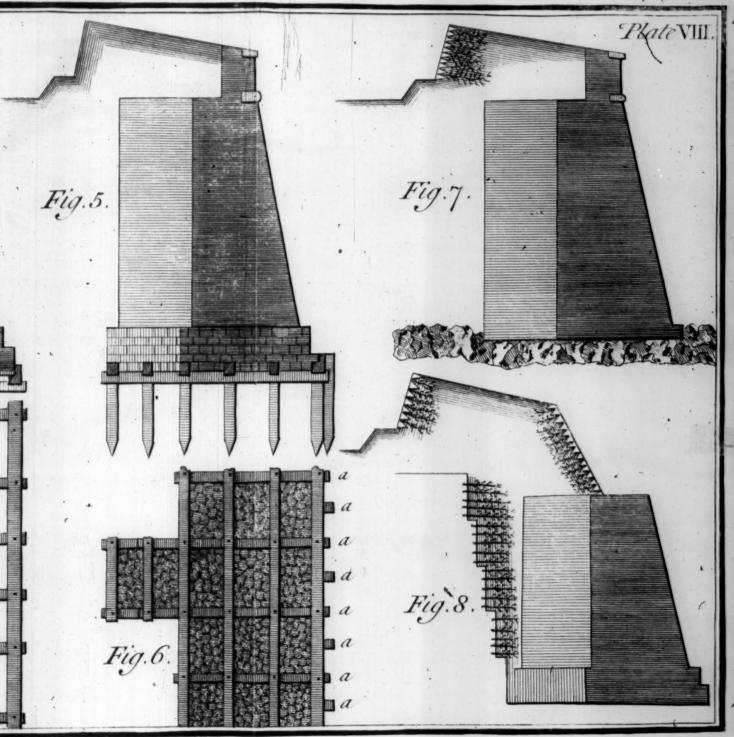
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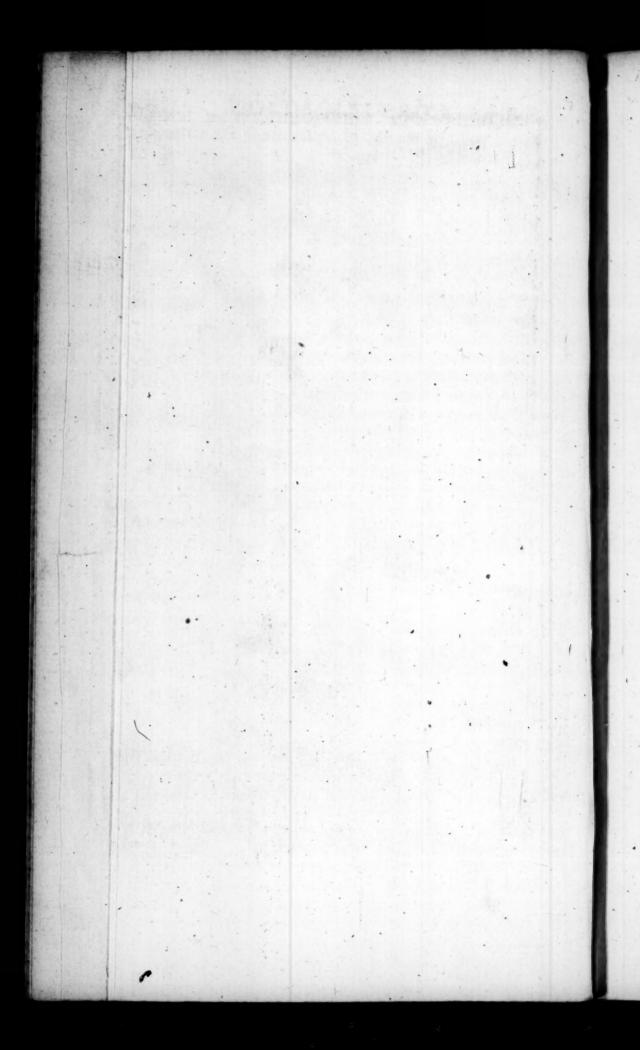
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Sect. 7. FORTIFICATION. 167 bours, will be treated of separately in the latter part of this work.

How to carry on the Works of a FOR TRESS.

The first thing to be done, is to know what part of a fortification is to be built first: Some engineers begin with the covert-way, and fecure it with pallifades, in order, they say, to prevent the enemy from disturbing them in carrying on the works: This reason may do in time of war, and in a place where the enemy can come at; but in a time of peace, it is entirely groundless, because it is a difficult matter to know exactly how much earth is required to make the rampart of the body of the place, and those of the outworks; and therefore by leaving either too much, or too little, the carrying it afterwards to their proper places causes a great deal of superfluous expences, entirely owing to

the want of skill in the engineer.

Others chuse to begin with the flanks, and then go on with the faces of the bastions, that in case an enemy should endeavour to disturb them, they might keep him off by means of the guns placed therein: This may do very well when the foundation is good, but would by no means be proper, where they are bad, for the reasons given before; because if one part should be built before the whole foundation is laid, it would be fettled before the next is finished, by which the last would break off from the former by its fettling: This will even happen, when the foundations are good; it is certain, that when the foundations are once laid all round, of about fix feet high, and well fettled; then the rest of the wall of the bastions may be finished first; and forafmuch, that when they are full, require a great quantity of earth, which is eafily carried through the curtains; whereas the earth for the ramparts of the curtains cannot fo well be carried through a paffage in the bastion; but, however, every engineer may have his

M 4

his particular reasons, for beginning the works sooner

one way than another.

When the foundations of the body of the place are laid, the first thing to be done is, the openings for the common sewers in proper places, to carry off the filth and rain water of the streets; and it must be particularly observed to give them a proper descent, from the center of the place towards the ditch, that the water may carry off the mud, otherwise they will soon choak up, and require continual cleaning; and they should always be carried either under or near the places where the bog-houses are to be made, that the water may carry off the filth, and prevent their stinking in warm weather, and their being nauseous to the inhabitants.

If there are any powder-magazines to be made in the bastions, or any other building, such as an hospital for the fick and wounded in time of a fiege, or storehouses to lodge ammunitions in, they must be built at the same time as the bastions; in order that there may be no useless removings or diggings of earth, which would create fuperfluous expences. If there are galleries for mines to be made in any of the works, they should be begun at the same time: In general, all under-ground works should be first considered, and begun as foon as the foundation of the walls are laid: For which reason, not only the plan and profils of a fortress should be made at first, but likewise, drawings of the most minute parts of all the necessary buildings, which depend on the fortress, with their dimensions marked upon them, and expressed in the estimate.

S E C T. VIII.

METHOD to be observed in making MASONRY.

TAving entered into all the most necessary particulars of the materials used in the building of a fortress, we shall now shew how they are to be applied in the best manner; and as stone masonry is by much the greatest part, we shall begin with that first, and then proceed with the rest, each in their order.

As masonry made of hewn stones is certainly the best, but at the same time so expensive, that few works are hardly ever wholly built with them; for which reason, engineers content themselves to make the lower part of the wall of them, for about 8, 10 or 12 feet high, as likewise the salient angles quite up to the top: and the hardest fort are chiefly used at the angles. and in those places where a strong current, or the sea can beat against them: For if the stones are not very hard, the water striking with a great velocity, in an oblique direction, wears them presently out; as may be feen at Portsmouth.

Masons distinguish their hewn stones by two names. viz. stretchers and headers; that is, suppose a stone to be twice as long as it is broad, then if it be laid fo as the length goes into the wall, it is called a stretcher, but if the length appears on the furface of the wall, it is called a header. These stones are laid alternately, a header, then a stretcher, through the whole length of the wall; and at the angles, that which is a header

one way is a stretcher another.

The engineer or his overfeers, ought to be very diligent, to fee that these stones are well squared, and when they lay them, that they bed well, that is, that they lay quite flat on each other; for the masons often are very careless in their work, either for the sake of speed, or out of meer idleness; and when the stones are laid, and bed not well, they put wooden wedges under the corners, to save the trouble of removing and squaring them a new; which should be prevented as much as possible; otherwise a wall can never be strong, and sirm, and therefore has not a proper strength to

refift the preffure of earth which is against it.

The ancients were so very nice in all their public buildings, that no joint scarcely ever appeared; which they did by rubbing the joining surfaces against each other, and laying the stones without mortar, leaving the outward surface rough, till the stones were all laid, and then making it smooth: But this precaution is never taken now-a-days, for which reason, no modern building comes up to those built by the ancients, either for beauty or strength: For you may see in the finest buildings in England, the joints in columns or pilaster, half an inch wide, filled with very bad mortar, which by the weather has been worn out in a short time, to the great shame of the modern architects.

The best stones being used in the facing, the rest is made with small stones, called rubble; but care must be taken, that this rubble work is well performed, in making the workmen choose those which lay close to each other, and that they fill up every part as well as they can, and not by a quantity of bad mortar, as they

certainly will, if not prevented.

If the walls are to be built in water, the stones must be laid with terrass mortar, those parts which are sometimes dry and sometimes wet may only be laid in tile or cinder mortar: when we say that stones are to be laid in terrass mortar, it is meant only round the facings, and the rest is filled up with good common mortar; because terrass is very dear, as little is used as can be; I would advise the engineer, to lay all the facings with cinder or tile mortar, if he intends to make stong work.

work. For the mortar commonly used in facing the works, is generally so bad, that it requires to be new done in very few years; which is not only expensive but likewise troublesome.

The bricklayers and masons content themselves with making the facing look well; for which reason, when they build by contract they make use of mortar, with very sittle lime in it, that is, no more than to keep the sand together; and when the wall is run up, they scrape a little out of the joints, which they point with a better fort; so that the wall looks as well as if it had been built in the best manner. The only reason I can find, for their making worse work here than any where esse, is, that most people in and about London build upon leases, so that they contract with the bricklayer to do the work, never troubling themselves whether it is well made or not; thinking if it but lasts their time it is sufficient.

This is what the workmen are so used to, that when they are employed, by the public, or government, it requires the greatest care and constant looking after them, to make them do better work.

The back part of walls, in ramparts and counter-fcarps, should be laid, for the depth of about two feet, in strong mortar, so as to dry soon; and the earth should not be laid against them before a twelvemonth; for if the wall is not well dried beforehand, the continual dampness of the earth will prevent it from drying afterwards; and this is often the case, that walls cannot resist the pressure of earth against them, which they otherwise in all probability would have done, had the work been set before the earth was laid against them.

The manner of building arches, and other works under-ground, requires some particular precautions, besides those mentioned already, which we shall mention, when we come to treat of these kind of works.

Mr.

Mr. Belider says, that hard stones should be laid in stiff mortar, and soft ones in soft mortar; which seems to me quite contrary to the nature of the thing: because the pores of hard stones being very small and close, the mortar cannot enter into them without being very soft and thin; on the contrary, soft stones have larger pores, and are very spongy, and therefore require a greater substance to unite them; whereas thin mortar will soon be sucked into the stones, without being able to unite them. This rule is observed by joiners, for when the wood is hard, they make use of thin glue, and on the contrary, in deal or other soft wood they use that which is thick and strong.

The manner of building with bricks is much the fame as that of building with stone; but it must be obferved, that as bricks cannot be cut to the slope of the wall, and are always made square; the bricklayers make the joints at the slope side bigger than within, in order to follow the proposed profil, which is a very bad practice; for the weather beats the mortar out of these wide joints, by which the wall requires to be new pointed every two or three years; we have instances enough of

this kind, not proper to be mentioned here.

Another defect arises from this practice, which is that the courses of the bricks length being at right angles to the slope, and the rest lie in a level, by which they make an angle, whereby the bricks can never bind so strongly together, as if they were all laid in the same plan; whereas, if the outward slope be made one sixth part of its height, and the courses perpendicular to that slope, and to lie in the same plan, the bricks will bind much better together, and make a stronger work; as likewise resist more the pressure of the earth, as we have observed before.

I know that some engineers, and most workmen, fay, that the courses of thone or brick should always be in a level, so as to bed well, otherwise, the wall will not support itself upright; but this is no more than a

conceit of the workmen, who will never go out of the old beaten road; for they do not confider that the prefure of earth endeavours to throw them forwards; and therefore, by opposing a greater force to this pressure, the walls must last the longer; what they say may do very well in civil architecture, but by no means in the

military way.

An engineer should always consider, what method answers best the proposed design, and never sollow the advice of others, unless it is agreeable to sense and reason; for he that sollows blindly the practice of those that went before him, will never become a good engineer: This may chiefly be the cause of making so few improvements in fortification; for whoever reads authors that wrote upon the subject some hundred years ago, will be surprised, to see what sew alterations have since been made, and these are, the most part, for the worse.

Another great defect in brick-work, is the large joints made with bad mortar; they are commonly three quarters of an inch, whereas, half that thickness is more than sufficient: A certain engineer piqued himfelf, to have all the courses exactly three inches; and as the bricks are two inches and a quarter thick, the joints were three quarters; but this ought not to surprize any body, considering the humours of the person, which are altogether extraordinary, as well as most of his actions.

Sometimes bricks and stones are used together, especially, in places where stone is scarce: This may be done to good purposes; for if the wall begins with stone to about six seet above ground, and then carried on as high with bricks, and over this, a bed of large stones is laid, then bricks, as before, and another bed of stones; it will make better work than bricks alone; because, stone being heavier than bricks, they keep the work better together by their own weight.

When

When large stones are scarce, the facings of walls are made of bricks, and the rest with rubble stones; but as it is hard to bind stones and bricks together, the work becomes very bad, unless great care is taken, to intermix them in a proper manner. The French engineers make the bricks go off from the facing towards the back part of the wall, in an edge, or like an inclined plan, and fill the rest with stones; this may be done another way, by carrying here and there a course of bricks quite cross the wall, of three feet broad, and two high, at proper distances from each other, which will bind the wall pretty well together. In short, the engineer ought to judge from the materials, and his own experience, what is best to be done upon all occasions.

SECT. IX.

Of CASEMATS and all forts of under-ground WORKS.

THE method of building the walls of underground works requires much more precaution, than those that are above, not only because they are to be bomb-proof, but likewise to keep out the damp or wet, that whatever may be deposited in them, as men, ammunition, and provision in time of a siege, may keep dry, and be preserved without any damage.

In small fortresses, there cannot be too many underground lodgements, because nothing can be secure otherwise; since the shots and shells can reach every part of the place, and destroy it: Therefore there should not only be a sufficient number of magazines that are necessary to lodge stores and ammunition, but likewise hospitals for the sick and wounded, and places to rest the fatigued soldiers, in a secure manner. Whereas

in large places, there is always some part or other which are secure from shells or shot, which may serve to lodge every thing that is not immediately wanted.

But before we enter into the particulars of their confiructions and fituations; it is necessary to explain the

manner of building them.

As we have but few works of this kind here, and most of them were built by such engineers as were not skilled in them; we shall insert the method pursued by the French, given by Mr. Belidor in his Science des Ingeniures; as knowing that he had it from the most knowing and experienced engineers of France.

We suppose, says he, that the masonry has been built with all possible precautions, that is, the stone or bricks to have been laid in mortar made of the best lime to be had, mixt with tile or cinder dust, and lest to thry a sufficient space of time before it is covered with a particular kind of cement, made according to

the following manner.

This cement is generally made of tourneys cinders, which is nothing else but the cinders, that are found in lime kilns, where they use coals, mixt with the small particles of lime stone: this is beat and prepared every four or five days, for the space of fix weeks; observing to put only a small quantity of water to it the first time, and none afterwards; or this cement is made with mixing one third of unflaked lime, the best that can be had, with two thirds of terrals, or instead of terrass two thirds of pozolano, or else old tiles well burnt, reduced into dust, and passed through a fieve: but whether the one or the other of these cements be used, the parts must be well reduced into duft separately, with a hand mill, and afterwards the two materials well beat and mixed together, and to repeat this feveral times without any water, excepting at first.

Before the cement is applied to the vaults, it is necessary that the masonry be well finished, and had a sufficient fufficient time to dry, which is reckoned to be about fix months; then the joints must be well cleaned with a small iron hook, after that the dust and dirt being fwept off very clean, some water is sprinkled over it with a water-pot; then the cement is laid over it, being well worked immediately before, of about an inch and a half thick every where, and as even as can be; which is beat all manner of ways with a wooden battle, of two inches broad only, in order to press the cement better into the joints; after that, it is made quite fmooth with a flat iron, such as are used for ironing linen, till it begins to be hard; and for some time it must be rubbed over with a mop dipt into cement made very thin, once every day, and then passed immediately over it with the aforesaid iron, to make it fmooth; and when this is done, it is covered with straw, to prevent the heat from cracking it; this work is continued till such time that no cracks appear in it: after that it is washed over for five or six days as before, without polishing or coverings.

In applying the cement, care must be taken, above all things, to make it smooth and even, and to terminate the upper part in an angle like a roof; and so as no stone appears through the cement. This being done, the cement is covered with a bed of gravel or coarse sand of sour or sive inches thick, laid every where very smooth and even; and upon this bed of gravel is said another of earth of about a foot and a half thick, well beat and rammed down; and then more earth is put upon it, and beat down; this is continued quite up to the surface of the ground: Mr. Belidor says, that the vaults in the tower-bastions of New

Brifac were built in this manner.

I should think, that if a bed of well-prepared clay of about six inches deep, was laid over that of the gravel, and over that one of earth, it would much better prevent the water penetrating to the cement, than earth only; as to the gravel, its use is to suck in the dampness

dampness of the ground above it, and to keep the moisture from the cement.

Mr. Belidor proposes another method, which, he says, has been used in the building of a samous orangery at Versailles, with great success, and which is as follows.

As foon the vault was made, it was well cleaned, and a bed of rubble stone laid over it, of 18 inches thick, without any mortar, only dust of lime thrown between the joints; upon which was laid a bed of the same dust four inches thick; and then a bed of pebble stone, and then another of slat stone of a foot deep; which was covered with another bed of lime dust of sour inches thick: this, he says, was continued to the very top, and even with the level of the terrass above it: This vault has stood hitherto the weather, without

the least change or alteration.

The same author says, that sometimes a bed of clay a foot thick has been laid over the first bed of stone. and one of mortar three or four inches thick over the laft. and then the earth. To fecure the piers of underground vaults against the water filtering through the earth, a wall of dry stone is made against them on the outside, of two feet thick, without mortar, the joints being filled with gravel or coarfe fand; and the wall is continued to within two feet of the roof of the vault; the rest being finished with good masonry, and covered with the bed of cement, which lays on the vault, and is extended over the wall: this precaution will fecure the piers from all dampness; but it ought to be observed, that this dry wall should be two feet lower than the foundation of the vault, in order to make a gutter for carrying the water into the ditch.

SECT. X.

Of SALLY-PORTS.

Plate IX. Ally-ports, or postern-gates as they are sometimes called, are those under-ground pasages, which lead from the inner works to the outward ones; fuch as from the higher flank to the lower, or to the tenaills, or the communication from the middle of the curtain to the ravelin. When they are made for men to go through only, they are made with steps at the entrance and going out, as may be feen in the first and fecond figures; it may be observed, that when the rampart is not of a sufficient height, as it happens here, it being but 15 feet high, the entrance has been funk 5 feet below the level, in order to secure the arch against shells; and the outside of the arch is circular as well as the infide, and not in the form of a roof, as Mr. Belidor would have it; because it is not possible to make them fo, unless the rampart is very high; neither can the infide of the paffage be above 6 feet wide, and the height but 8 and a half, otherwise it will not be covered with a fufficient quantity of earth to fecure it against accidents.

There is always a gutter or shore made under the sally-ports which are in the middle of the curtains, for the water which runs down the streets to pass into the ditch, as we have marked in the sirst profil; but this can only be done when there are wet ditches, because the water would settle in dry ones before the sally-port, and make it difficult to go out and in; besides, the smell of this dirty water would become very offensive in

warm weather.

These under-ground passages are secured by two strong doors, the one at the entrance and the other at the going out; the outside of the passage is generally walled

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walled up in time of peace, leaving only an opening like a window to let the air in, that it might not be too damp, and rot the doors. The fide-walls, or piers, as well as the arches, are two feet thick above, and two and a half near the foundation; there being no occafion for counterforts, as Mr. Belider has them; the wall being of a sufficient strength to resist the pressure of the earth, as we have found by computation. The white space above the arch in the first sigure, terminated by two parallel lines, represents the crust of cement laid over it, and the dotted space above this, the bed of dry stone, spoken of before: the front wall at the entrance is raised three feet above the rampart, to prevent people from falling down in the dark.

At the sides of these passages, powder-magazines are often built, which are very necessary, for having stores and powder nigh at hand to transport them into the outworks in the time of a siege; they are made in proportion to the quantity of stores wanted. Those marked in the second sigure are 15 feet by 18; but it must be observed, that their width depends also on the height of the rampart; because there must at least be 3 feet of earth above them, in order to make them bomb-proof. The walls as well as the arch are but 3 feet thick, sloping at the outside, so as to be but four near the foundation, without any counterforts.

When fally-ports ferve to carry guns through them for the outworks, instead of making them with steps as is represented in the first and second figures, they must be made with a gradual slope, as is represented in the third and fourth figures; and they must then be 8 feet wide: If the rampart is but low, the arch may be made elliptical; in short, in the building these passages, regard must be had to the profil of the rampart, and to the use they are intended for, whereby the pro-

per dimensions may be determined.

When they are made with a gradual slope, the bricks of the piers or side-walls must be made by ho-

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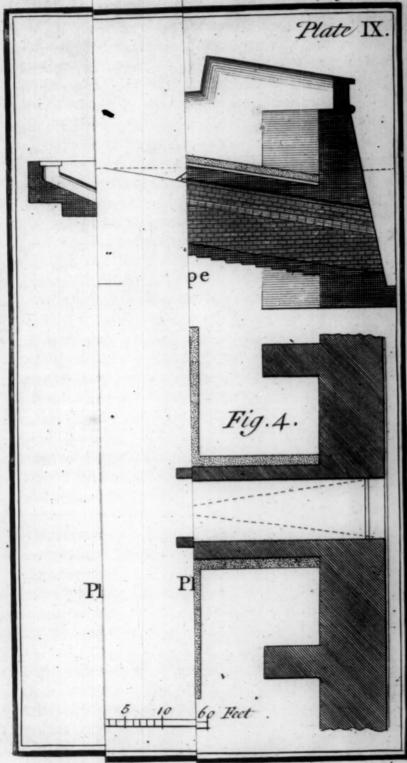
rizontal

rizontal courses, as high as the spring of the arch; and the arch itself perpendicular to the slope, in the manner represented by the third sigure: there are two folding doors, one at the entrance, and the other at the going out, that they may leave a free passage for guns and other warlike engines, and sometimes several of these doors are made, in order to defend the passage; for which purpose, wickets and loop-holes are made in them, to retire through and defend them one after another.

The walls are about two feet and a half near the foundation, with a flope on the outfide, so as to be two feet only near the spring of the arch, and the arch itself is but two feet without any counterforts; because the weight of the arch is sufficient to counterbalance the pressure of the earth. The magazines on both sides of this passage are 14 feet square, and the walls are half a foot stronger than the others. The top of the arches of both the passage and the magazines are covered with a crust of cement, and above this with dry stones, as well as the side-walls, in the same manner as has been mentioned before.

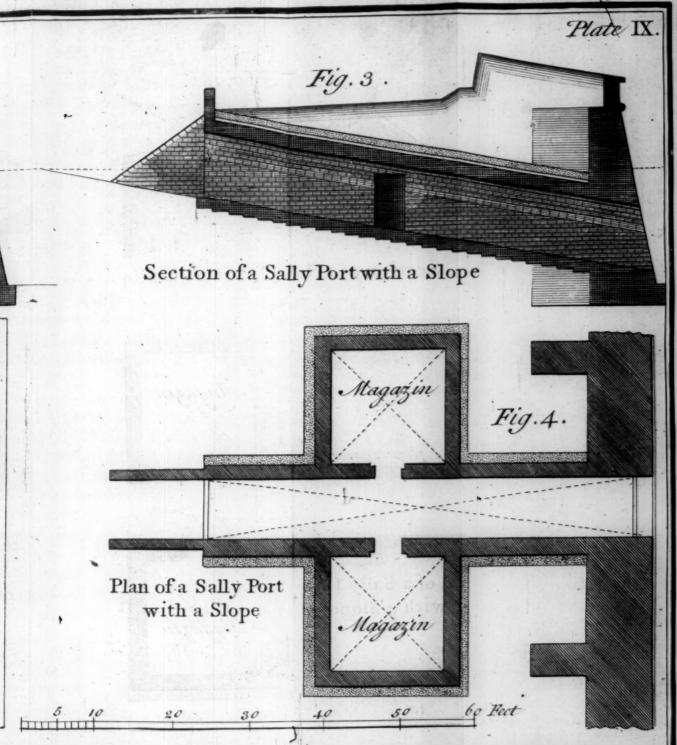
In fortresses where a river passes through the ditch, such a passage as the last is made to water the horses; which are sometimes walled up in time of peace, and at others lest open, with a strong gate to lock them up at night; but as they are the same as the former, we shall say no more about them. As to the soundations and many other particulars relating to these passages, we shall leave them to the judgment of the engineer, who is to consider well beforehand all the conveniencies, and every minute circumstance, before he begins the work.

It is customary to build hospitals for the sick and wounded, under the level ground of the bastions, as likewise powder-magazines, store-houses, and ovens to bake the bread; these buildings consist of a long passage from the center of the gorge towards the sali-

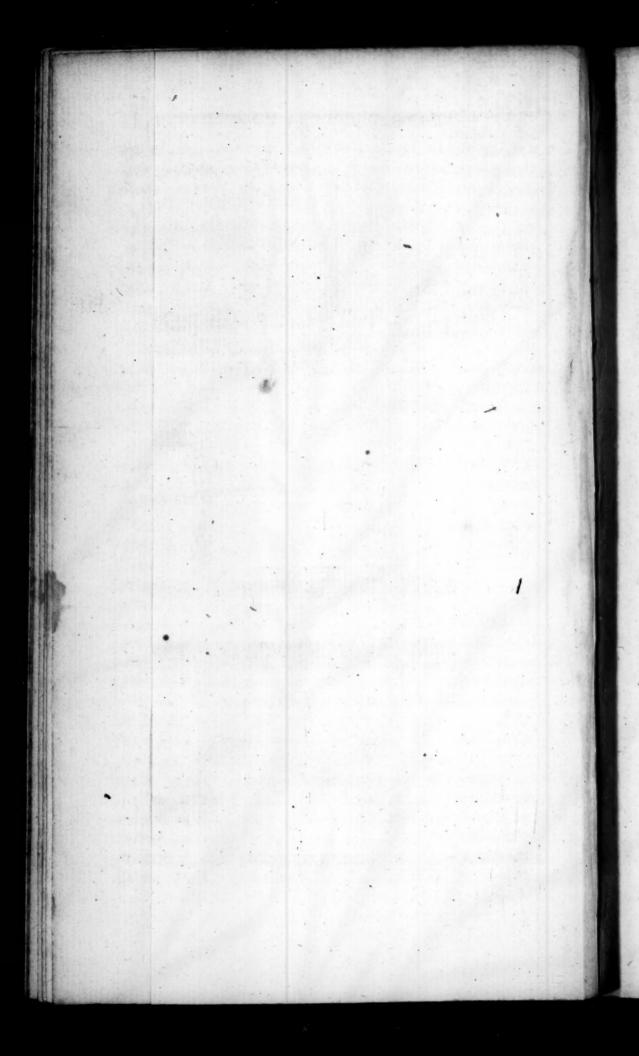


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9: Couse Sculp .



ent angle, with as many rooms on both sides as are thought necessary; some of them have chimnies, and others air-holes coming out within the bastion; these buildings are especially made when there is a cavalier in the bastion; because they need not then be sunk under the level, there being always a sufficient quantity of earth above them, to resist the force of the shells. These works are built in the same manner, and with the same precautions, as the former.

SECT. XI.

Of CASEMATS in the RAVELIN.

As we esteem the ravelins to be the most essential of all the outworks of a fortress, so we think that nothing contributes so much to a long and stout defence, as the making them capable of all the resistance that is possible: For a town defended as it ought to be, can never be taken, till such time the enemy is master of the ravelin in the front attacked. Coeborn and some others have made their ravelins with casemated slanks, but for what reason is unknown to me; though several pretended engineers look upon them as considerable works: It is therefore worth our while to examine their use and perfection, in order that young engineers may not be missed by the erroneous opinions of their superiors.

As these slanks cannot defend the ravelin, in which they are, their intent must necessarily be to defend some other work: which can only be the breach in the faces of the bastions opposite to them; the passage of the great ditch, or the covert way: But as the ravelin in the front attacked, is either taken, or its defence destroyed by shells, and the ricochet batteries, before these works are or ought to be attacked, it is evident, that these slanks in the front attacked can be of no use

at all. Neither can those of the ravelins in the fronts, adjacent to that attacked, be of any use, since but a few of the guns placed there will bear upon the attack; and the besiegers have always ricochet batteries to destroy the desences of these works, which see the attack, as may be seen in the fixth plate of our attack; besides, the same batteries which batter the breach in the bastions, will see obliquely these slanks; or the most trouble these slanks can cause, is to oblige the besiegers to raise two batteries of four guns each, in order to destroy them. I leave it therefore to the judgment of the reader, whether it is worth while to make these expensive works, for so little a purpose, or whether some others might not be made of a much better desence, and of no more expence than these.

Notwithstanding that the ravelin in the front attacked at Bergen-op zoom, had casemated slanks, yet the French took both bastions and ravelin at the same time, without given the besieged time to fire a gun from them: this was not so much owing to the bad construction of the works, as to the unskilfulness of the defenders, or to something else not proper to be made

public.

Plate X. The best way to secure the ravelins, when the ditches are dry, in my opinion, is to make redoubts in them, with a parapet of about 12 or 15 feet thick only, and about two feet lower than that of the ravelin; that thickness is sufficient, since it can only be seen from the rampart of the ravelin: and if the counterscarp be casemated in the manner marked with dotted lines in the plan, Fig. 1; and as the plan of the works shews in the second sigure; it appears to me a difficult matter for an enemy to get possession of it.

That there may be a secure communication from the works in the redoubt to those in the ravelin, and from thence to the covert-way; traverses are made in the ditches, marked L, L, in figure 1. or l, l, in the section, fig. 3: These casemats have two entrances,

marked

marked E, E, in fig. 2, from the ditch or the caponier usually made from the opposite curtain to the gorge of the ravelin; as well as two stair-cases, marked D, D, in the same figure, to mount into the redoubt, as likewise two more in the level ground of the ravelin, not marked here; so that if the enemy gets possession of one side of the ravelin, the garrison may sally out through the other; or when the redoubt is lost as well as the under-ground work on one side, they may retire through the other.

As the beliegers can no other ways get possession of these works, than by mines; openings must be lest in the great gallery A, A, at proper distances, for countermines to be carried on all the way under the ramparts, and behind the parapets, to resist the enemies miners; as likewise to oppose every attempt they can make, both above and under-ground, in such a manner, as to make it equally hazardous wherever they may choose

to affail the work.

The openings of these galleries into the ditches of the ravelin and redoubt must be well secured with strong doors, full of iron, and behind these others with wickets and loop-holes, to retire behind, and to defend the entrance that way, in case the enemy should attempt it; as probably he would if they were not well secured.

The walls of these under-ground works need only be about two feet thick near the soundation, with a slope on the outside, so as to become a foot and a half near the spring of the arches; this will be sufficient, because the arches will secure them against the pressure of the earth. The piers which separate the lodgments B, are not so much made to strengthen the wall, as to prevent the arches from being too high, which may be elliptical or parts of circles. These lodgments are so feet wide, that is, as much as the great gallery is broad, in order that the arches may join well; and N 4

the base of the piers are 8 feet long; so that the whole breadth of the great gallery and the lodgment together is 18 feet.

The bottom of this gallery must be about 18 inches above the bottom of the ditch, in order to secure it from dampness, and the piers are 7 feet high, with loop-holes between them, which look into the ditch, to give air to the lodgments: as to the rest, the plans and section sufficiently shew our meaning, without being necessary to enter into any farther explaination: The only thing to be farther observed, is, that the arches at the entrance E, and over the stair-cases D, must be made conical; as to the others, the reader

may eafily perceive how they ought to join.

Mr. Coeborn made fuch galleries all round his counterscarp at Bergen-op-zoom, with loop-holes to fire into the ditch, and at the re-entring angles of the places of arms, lodgments nearly fuch as are marked here, which he called Tambours: and to secure the entrance above ground, he made a traverse on each side of the stairs, as likewise placed a row of palisades. As these lodgements made the best defence of all his works, in the last siege; it is plain that they are very advantageous in a fortress; but as to the gallery round the counterfcarp, it was of no other use than to lodge the troops fecurely from danger, and to carry from thence galleries for mines under the covert-way and glacis. For which reason, I would either choose to make none or one of about 6 or 8 feet wide, which would fufficiently answer the intent proposed; and besides, would cost very little more than a fingle wall with counterforts: there might be some wooden doors placed at proper distances, with loop holes, so that if one part was taken by the enemy, the defenders may retire fecurely into the others.

As to the casemats under the places of arms, they ought by no means to be neglected; and to secure their entrance above, there should small redoubts be made

of 12 or 15 feet parapet, and a dry ditch before them; by this means the places of arms may keep off an enemy a long while, and make them pay dear if they take it; as it happened to the French at Bergen-op-zoom.

It may be observed in general, that a fortress without under-ground works can make but a small defence now-a-day, against the great quantity of artillery with which armies are furnished at present; for the defences above ground are soon destroyed thereby: therefore an engineer, who undertakes to fortify a place, must make use of all his skill and knowledge, to construct such under-ground works, as are best adapted to the nature of the situation; and to be as saving as possible, because these kind of works are naturally very expensive.

SECT. XII.

Of CASEMATED FLANKS.

Plate XI. MESS. Coeborn and Vauban were very fond of casemated slanks, the former made some in the ravelins at Bergen-op-zoom, and the latter in his tower bastions at New Brisack; they have been in great esteem formerly by most engineers, and a fortress without them was not thought to be of any strength; but now-a-days they are generally rejected, because experience has shewn, that the smoak becomes soon so troublesome as nobody can bear it, notwithstanding all the chimnies and air-holes that can be made to prevent it.

As the only objection against these casemated slanks, is their smoaking, engineers have endeavoured to find some remedy or other for it: but that proposed by Mr. Belidor seems, in my opinion, to be the best, and is what has been practised in several places, as I am told, and have seen myself at Portsmouth, near the sea;

which

which is, to leave them open behind, in the form of piazzas; fo that each gun has an arch over it, as the plan, elevation, and fection, in the eleventh plate shews by the letter B; and the embrasures are marked by the letter C, which are Mr. Belidor's own draughts; he supposes the thickness of the front wall to be 18 feet, and to be of folid masonry; but as this would be very expensive, and seems to be useless, I would only make a common wall, and line the embrafures with brick, the rest being filled up with earth in the same manner as other parapets, as we represented by one half of the plan: I faid, that the embrasures should be lined with bricks. because they, being softer than stone, do not splinter so much, and the shots make only holes, without breaking them fo foon as if they were made of stone. Above these casemats Mr. Belider proposes to make another battery, as may be feen in the fection at A, annexed to the outfide elevation: but in low ramparts, fuch as we propose, it will hardly be possible, and therefore this upper battery may be left out.

This method of making batteries may be of great use near the sea or great rivers where large ships can approach pretty near; for they generally place men on the top mast round, which, being higher than the parapets of low batteries, gaul the gunners in such a manner with small shot, that they cannot stand to their duty; this is, as I take it, the reason, that ships always get the better of land batteries, and not the superiority of guns, as the mariners imagine; whereas, if the batteries were arched in the manner proposed here, it would be quite other-

wife.

Another observation is to be made, in regard to these casemated batteries, which is, that if the piers were broader near the parapet, than at the other end, and the arches conical, so as to open more behind, the smoak would evaporate in a freer manner, than if they were cylindrical; it is true, that the construction of conical arches is more difficult, and not very common, but an

engineer should never consult the easiness of the performance, but rather the perfection and usefulness of the work.

If this manner of building batteries near the sea, or navigable rivers, should be thought too expensive upon some occasions, it will be sufficient to make sheds over them with planks or even with canvass, to prevent the gunners from being seen, when they are upon the battery; for as they are in no danger of shells, any thing that covers and hides them will answer the purpose; but the case is different in slanks, because what the shot cannot effect, the shells will do, if no precautions are

taken against them.

As we are treating of flanks, it will be proper to confider the construction of the embrasures; whose common form is, to make them narrow within and wide without; fo as to enable the guns to fire not only directly, but likewise obliquely: this method has been objected against by a late author, faying, that the embrasures are fooner destroyed this way than if they were narrow without and wide within. But as this author has very little knowledge in gunnery, notwithstanding his boasted experience, he did not know that it was impracticable to move the guns fide-ways, from one fide of the embrafure to the other, as the nature of these embrasures require: whereas the field carriages, having only two wheels, are easily directed to the right or left, as occasion requires, when the embrasures are narrow within and wide without: This gentleman, feeing loopholes made in this manner at Bergen-op-zoom, imagined, I suppose, that cannon were as easily managed as muskets, with which he is best acquainted.

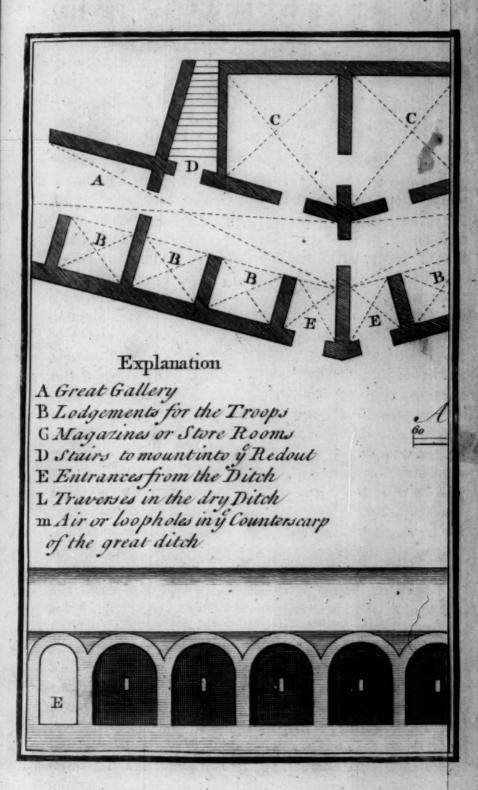
SECT. XIII.

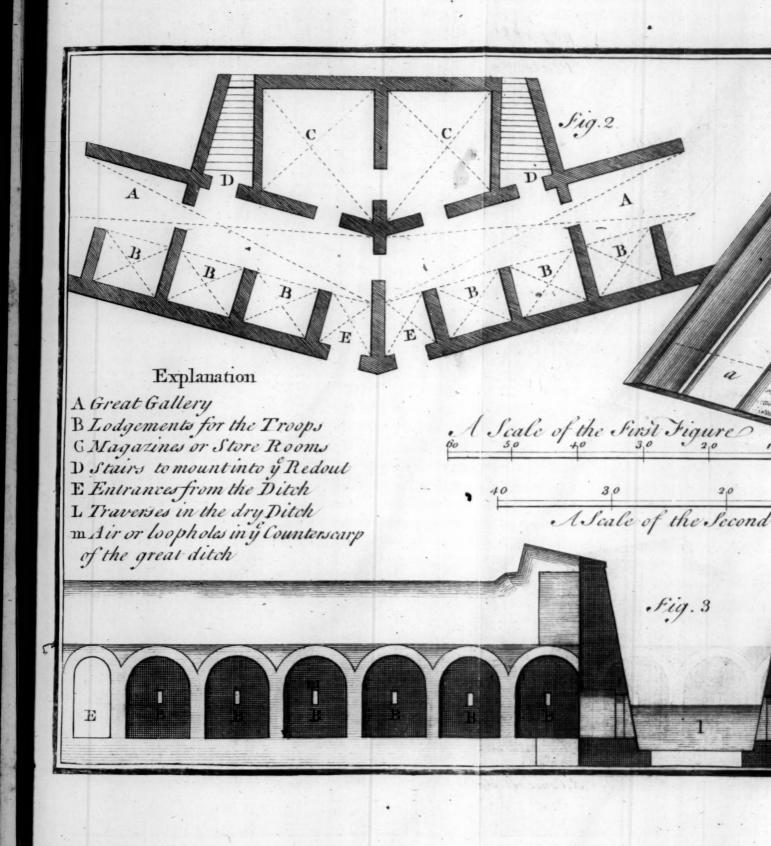
Of CAPONIERS.

CAPONIER is nothing else but a paffage made in a dry ditch from one work to another; when they are made from the curtain of the body of the place to the opposite ravelin, or from the front of a horn or crown-work, they have a parapet on each fide of feven feet high, floping in a glacis on the outfide to the bottom of the ditch; the width within is from 15 to 18 feet, with a banket on each fide: there is a brick wall to support the earth within, of a brick and half above, with a flope of a fifth part of the height; this wall reaches only within a foot and a half to the top; to prevent grafing shot, from driving the splinters amongst the defenders. These caponiers with two parapets may properly be called double; for there are some made with one parapet only, in dry ditches of the ravelin, and in that of its redoubt, towards the falient angles, and open towards the body of the place; it is true, that these single ones are also called traverses, but differ from the traverses in the covert-way, by their tops floping in a glacis to the bottom of the ditch, whereas the others are made in the form of all other parapets.

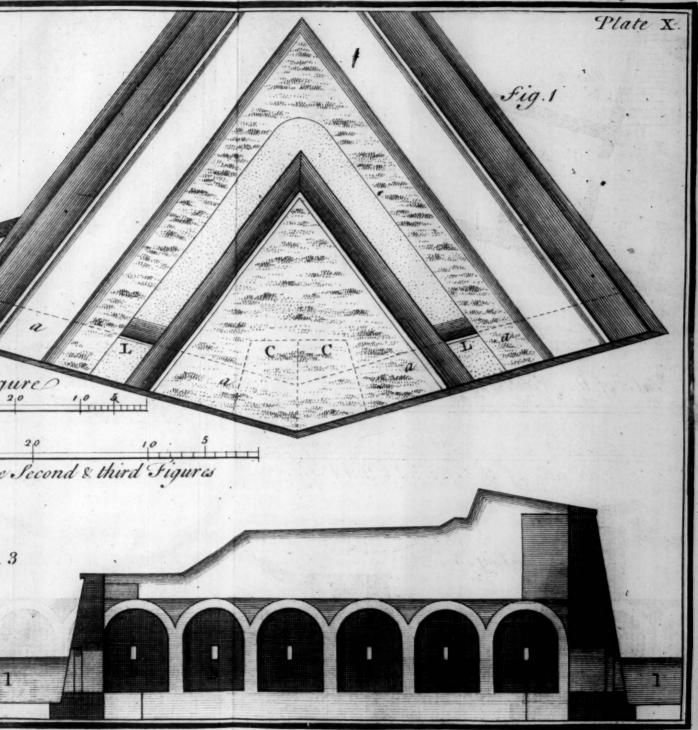
Caponiers made from the body of the place to the outworks, are sometimes arched over, with loop-holes to fire into the ditch; they have likewise doors on both sides for a communication from them into the ditch; because the besiegers never fail to destroy them by shot and shells, to render the passage more dangerous. The single ones in the ditch of the ravelin and redoubt are likewise made with arches open towards the place, such as we have spoken of here before; by making them in this manner, the guns which defend the ditch

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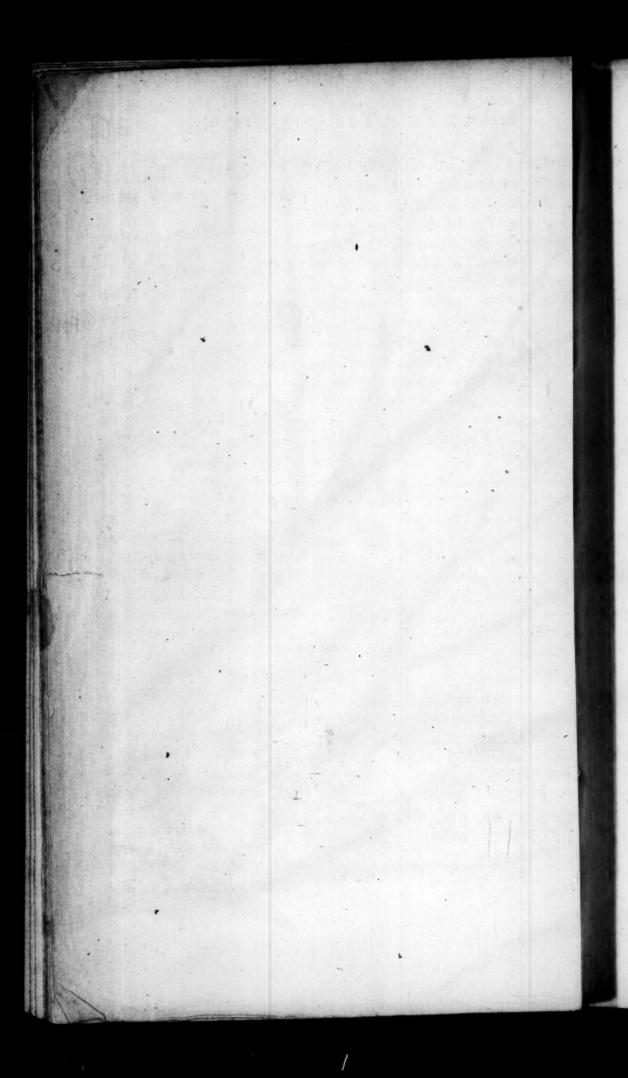




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J. Couse Sculp.



before them can no other ways be difmounted than by mines, and when they are so low as that no mines can be made under them, the enemies passage over these

ditches becomes very dangerous.

To make the passages or communications from one work to another, so as not be interrupted in time of a siege, or destroyed, is the most difficult part of fortification; for when the retreat out of a work is cut off or made dangerous, the troops in them neither will nor can desend them with so much courage and bravery as they would do otherwise; and this is the reason that an enemy always endeavours to destroy them; and should likewise engage engineers to prevent it.

SECT. XIV.

Of Town-GATES and GUARD-HOUSES.

THESE gates are made various ways, fometimes there is only an open passage cut in the rampart, shut up by a strong wooden gate, or with a drawbridge; and at others, this passage is arched all over, with a guard-house within, and a draw-bridge and a gate on the outside; the outside front is generally ornamented with pilasters and a pediment; the decoration chiesly depends on the taste the engineer has in architecture.

As we have no author that has wrote on military architecture, nor any of our fortresses, that I have seen, has any works of this kind worth mentioning; I was obliged to have recourse to Mr. Belidor's Science des Ingenieurs, which is the only work that treats of these things, in the modern taste; for what is to be found in Dilichius, Spekel, and other old German authors, is of so grotesque a taste, as scarcely would be followed now-a-days. But as the French are so magnificent in their military buildings, and the designs of this author

are chiefly adapted to large fortresses, which are not in use, nor necessary in this country; we have endeavoured to make ours in such a manner as will most probably

be of use to our engineers.

Plate XI. Our first design in this plate is quite plain; the width of the passage is ten seet, and arched above; at the entrance within is a guard-room for the soldiers on one side, and one for the officers on the other; each of these rooms is twelve seet square, having a window in the front, two seet and a half from the ground, three seet wide, and six high; for it is a general custom in all buildings to make the windows on the ground floor twice as high as they are broad; the chiminies are four seet wide, and a foot deep, half of which is taken out of the thickness of the wall and the other projects into the room, and is supported by piers of a foot thick: the doors are three seet wide and seven high.

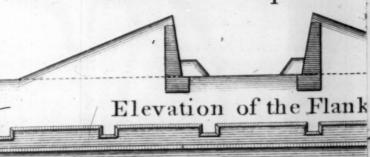
The walls of the passage which support the arch, are eight feet high, three feet thick near the foundation with a slope on the outside, so as to be two feet and a half at the spring of the arch, which is also the thickness of the arch itself; the walls of the guard room are two feet thick only, and the height of the elevation

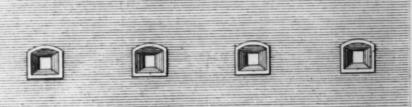
from the bottom to the roof is fifteen feet.

I have made no counterforts to these walls, because the pressure of the earth, together with the strength of the wall, will be sufficient to resist the pressure of the arch. This arch, as well as all those mentioned hereafter, must be covered with a bed of cement and dry stones over them, as has been mentioned before, where we have treated of this subject.

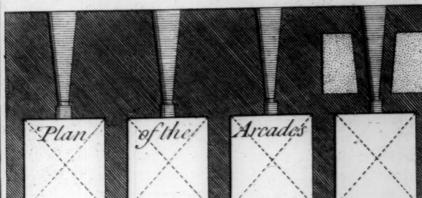
The outfide of this passage, that is next to the ditch, is shut by a strong wooden gate covered with iron bars and rails, so as not to be cut open by any tools; and if it be thought necessary, a draw-bridge may be made; but as this gate is designed for a small fort only, there is no occasion of making any ornaments that require

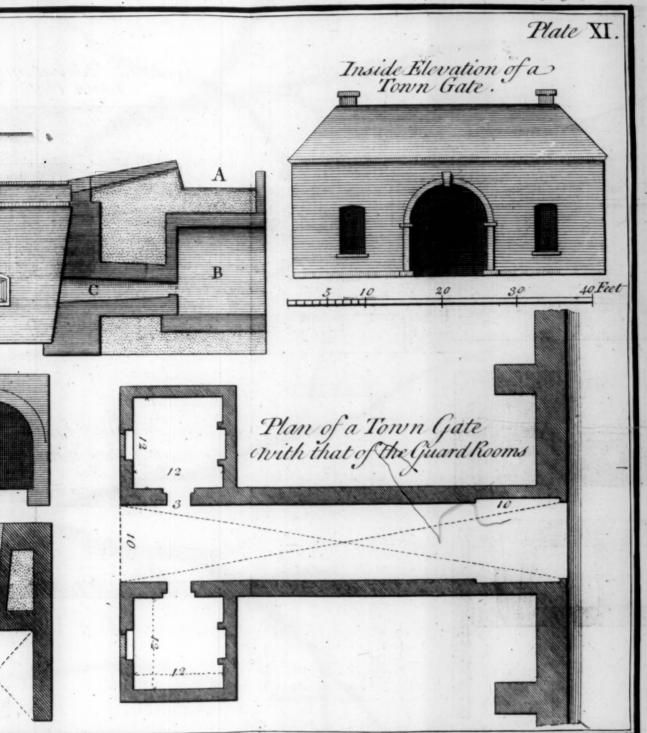
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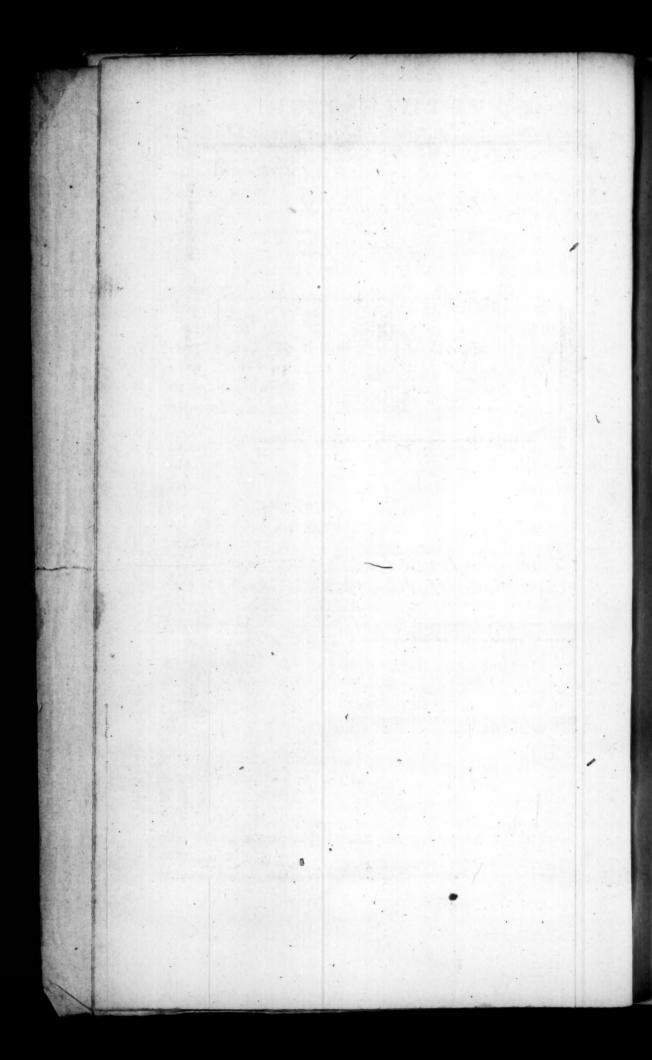








J. Couse Sculp .



much expences; for which reason, a plain wall with a

pediment will be fufficient.

Plate XII. As the outsides of gates are made various ways, and those in ravelins, horn or crown works, are different from those of the body of the place, because the passages are not arched, but always left open above; we have given here three different forts; the first is quite plain, and may serve for any outwork: it is composed of two piers of 24 feet high and 7 broad, with a base of two feet high, having a cornish and round balls above; the opening in this and the two following ones, is 10 feet: The first figure represents the elevation, and the second the ground plan, with the slopes and projections; there is a draw-bridge to this gate, the section of which is represented in the elevation.

The third figure represents likewise the elevation of a gate in an outwork, made in a more expensive manner than the former: For the two piers are of hewn stones, ten feet broad, and 27 high; each of them is ornamented with two pilasters, made according to the Tuscan order; that is, the height is six times their breadth, the plinth or base is half the breadth high; as is likewise the torus or moulding next to it, with the fillet:, And if we suppose the breadth of the pilaster to be divided into 24 equal parts; the astragal and fillet is one and a half of these parts, the gorge 4, the next fillet one, the quart de rond 3, the abacus 3; and the last fillet one; the entablement is 30 of these parts: The fourth figure represents the ground plan, with the slopes and projections.

The third gate, represented by the fifth figure, is designed for the body of the place, when the passage is arched; the width of the gate is 10 feet, the height from the bottom to the spring of the arch is 8, but may be from 8 to 10 or 12; the distance from one wall to the other 14, and their height including the cornish 30, and 12 broad; as to the pilasters, pedi-

ment and mouldings, they are the same as before, and the pediment is from one third to two ninth parts of its base high: The pediment ought to be ornamented either with the king's arms, or with military ensigns, and above the gate under the arch, which joins the piers, the arms of the city, or else of some particular person of note, who has mostly contributed to the

building of the place.

These are only a few specimens of gates, to give the young practitioners an idea of these kinds of work; the proportion of the parts may vary as well as the ornaments; but when there are pilasters or columns, they must be constructed according to the dimensions of the order, they are made of: We have made use of the Tuscan order as being the most simple; but a young engineer ought not to content himself with what has here been given, but apply himself to that part of architecture, which is most useful; and if he wants gates of a finer taste, he may consult Mr. Belider's Science des Ingenieurs, where he will find a great variety

and well-chosen examples.

Gates of large fortresses require more attention, than those of small ones; they must not only be secured with draw-bridges, but with port-culiffes, harrows, A port culifs is a wooden gate well coor organs. vered with iron, with sharp points, drawn up in a daytime by pullies, and let down at night: A harrow is a gate made of timber, whose dimensions are commonly 6 by 4 inches; and 6 inches distant from each other. well fastened to three or four cross bars, and secured with iron: And an organ is a wooden frame, with double bars, through which the timbers slide and fall down: the organ differs from the harrow in that the timbers are not fastened together, and is often preferred to the harrow on that account; because it is said, that if an enemy cuts one timber to pieces another may immediately be let down, which cannot be done in the harrow.

Plate XII. Fig.5. 40 Feet 5 20

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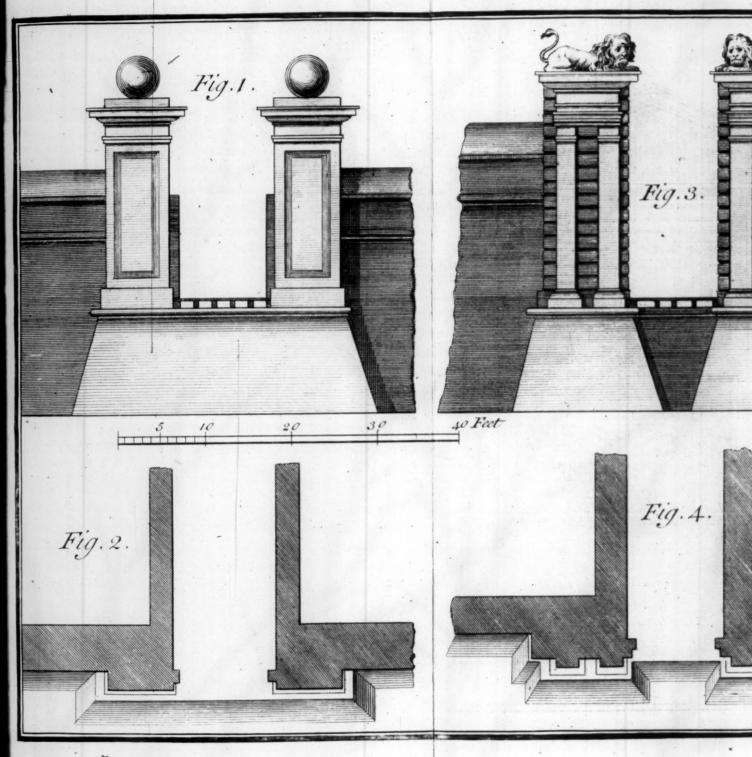
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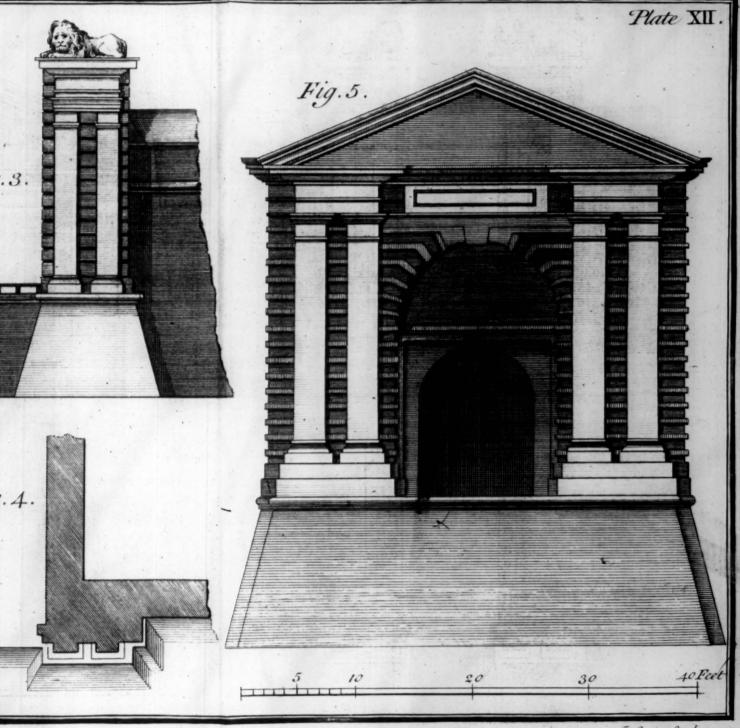
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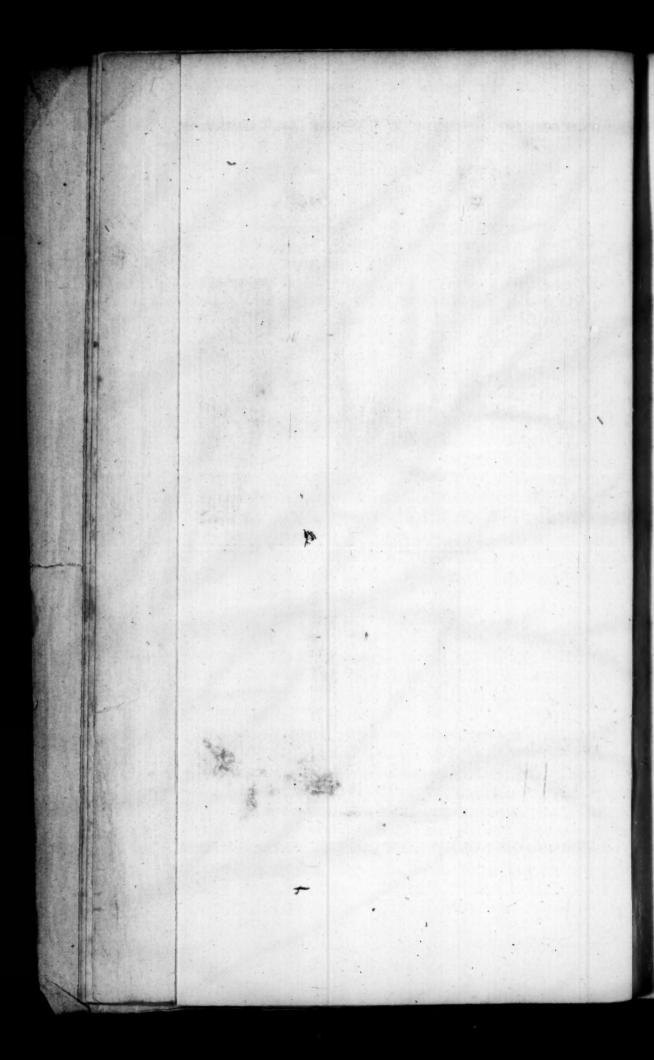
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The port-culifs, harrow, and organ, ferve all for the fame purpose; that is, to stop an enemy in case he has found means to let down the draw-bridge; either the one or the other may be used as the engineers think proper, and sometimes two of them, that if one has been cut or burnt, the other may serve to stop the enemy.

But to leave nothing which may give a clear idea to beginners, we shall give some designs of these gates when we come to treat of draw-bridges, barriers and

other things of that kind.

Plate XIII. As we have given one example only of a town-gate, which is very plain and simple, we shall present the reader with another, that may serve for the body of the place, which, though plain, yet is, in my opinion, sufficiently ornamented; it is composed of an arched passage and two piazzas at the entrance, for the conveniency of foot passengers, to get by carriages that enter or go out; at the left side of the entrance is the guard-room for the soldiers, and at the right the room for the officers, and as this last need not be so large as the former, a prison is made, so as to make both sides of the passage alike: above these rooms, and over the gate, are lodging-rooms, for the town major, and some other officers.

The passage is ten feet wide, and the projections to form the cavity for the port-culis, as well as those on both ends, are six inches; the thickness of the walls or piers which support the arch is four feet near the foundation reduced to three above near the spring of the arch, and are 8 feet 6 inches high, and the arch is three feet thick. The length of this passage, and that of the former depends on the thickness of the rampart, for which reason, they are not determined; the piazzas at the entrance are 9 feet wide, and 12 deep; the piers which support the arches 5 feet each way; the guard-room for the soldiers is 20 feet long, and 14 deep, with two windows of 2 and a half or 3 feet

wide, and as high again; the chimney 4 or 5, and the door 3 by 7: The officers room is 10 ½ feet long, and 14 deep, and the prison 8 by 14; the walls of these rooms are 27 inches or three bricks thick; the wall between the officers room and the prison is a brick and a half only, and the chimneys 4 feet wide; as to the windows and doors they are the same as the others.

As this building is too large to make it but one story high, it was for this reason we contrived the abovementioned lodging rooms above it: the elevation here is that of the inside or entrance, in which we could not represent the chimneys for want of room in the plate: The fifth figure of the last plate is the elevation of the outside next to the ditch; to this front is annexed another building, the lower part of which serves for the bascul of the draw-bridge, and the upper, to receive the port-culiss: The section through the length of the passage shews partly the nature of the building, whose breadth is equal to that of the passage and walls.

As the infide and outfide buildings do not join above, there is a passage left between them for a free communication upon the rampart, from one side to the other; that part of the arch is covered with a bed of cement, and dry stones over it, with three feet of earth besides. In this section is also seen the side of the wooden frame ab, called bascul by the French, which is fixed to the draw-bridge, by one end b, with a chain at each side, each passing over two pullies or rollers, turning upon an axis at the other end a, and is a kind of counterposse to the draw-bridge, to raise and let it down by; the particulars of which shall be explained hereafter, where we treat of draw-bridges.

There are stone steps made at the sides of the inside building to mount upon the rampart, which are not marked here in the plan, but are necessary, because there is always a sentry placed there at night; besides, when there is an alarm, that the guard may mount

quickly, and without any obstruction.

Plate XIII. Plan of a Elevation of a Guard House -00 Sectio of th

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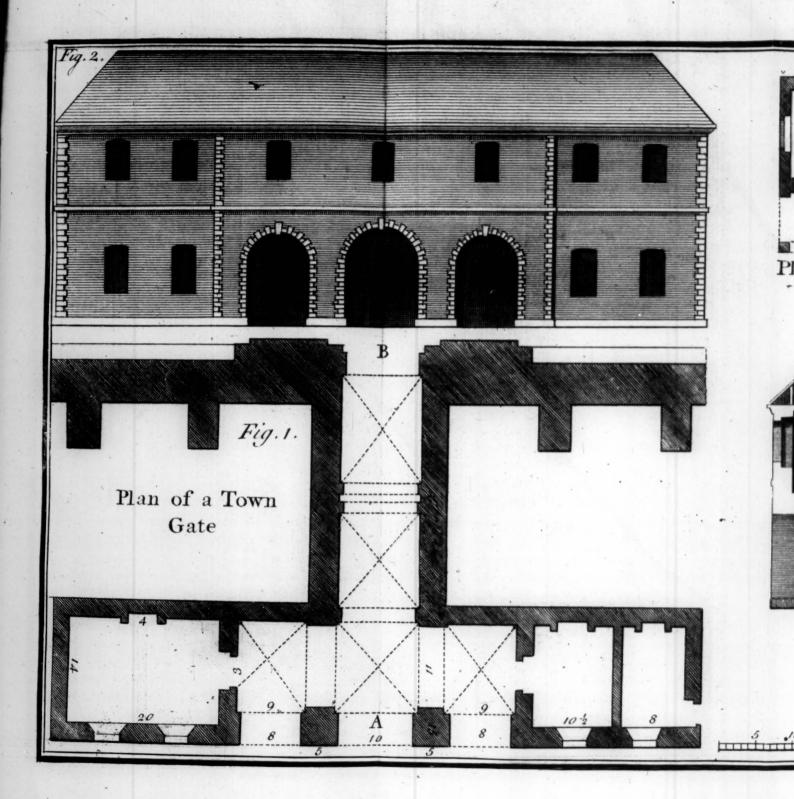
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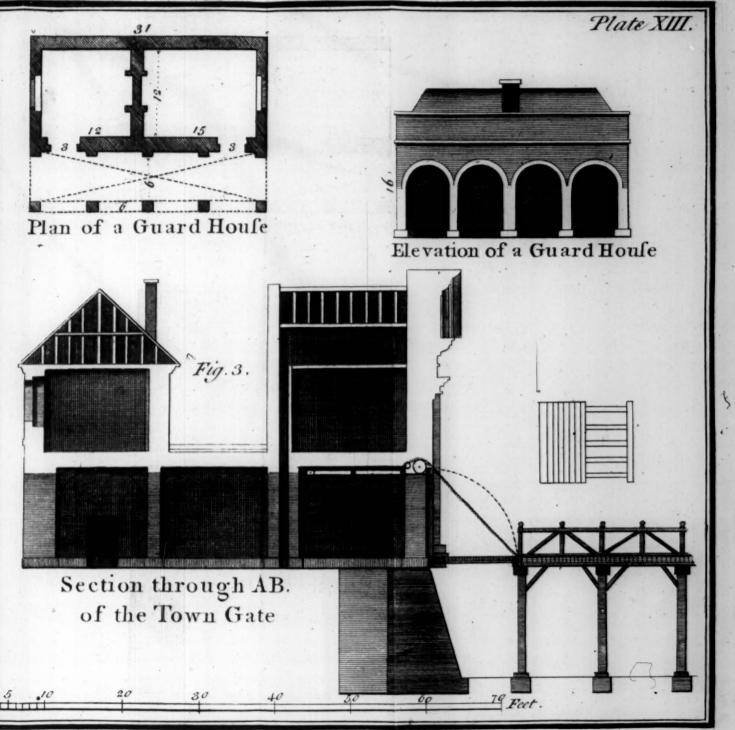
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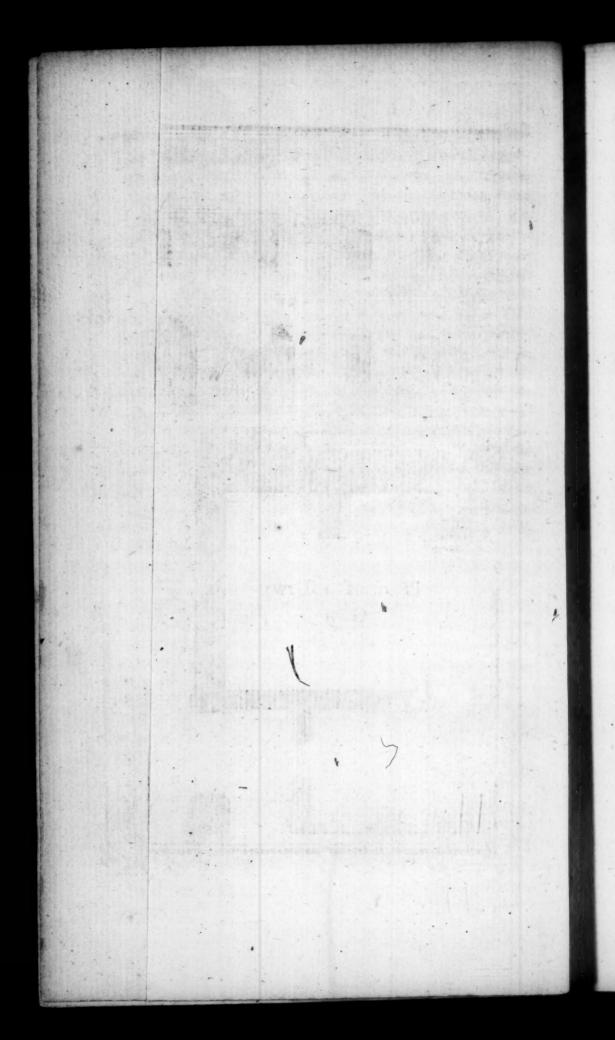
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J. Couse Sculp.



At the entrance of a fortress, and in the works that cover the gate, such as ravelins, horn or crown-works, are guard-rooms built, for the party without the inner gate, and which are shut out at night by the draw-bridge in the curtain of the body of the place: These buildings consist of two rooms, one for the officer, and the other for private men, as the plan and elevation in

this plate shews.

The officers room is 12 by 12 feet, and that of the private men 12 by 15; and there is a piazza of four arches before it, of 6 feet broad, and as long as the building, for the fentry to walk under in hot and rainy weather; the arches are supported by sive piers or pillars of about 15 inches square, and at 6 feet distant from each other: the wall is two feet thick, the windows 3 wide, and as high again; the chimneys 4 feet wide, and the doors 3 by 7; the elevation is about 16 feet high, including the parapet wall of the roof: The piazza may be made arched or slat roofed, according as it is thought proper by the engineer.

S E C T. XV.

Of BRIDGES.

Plate XIV. THE next works in order are the bridges of different kinds, such as draw-bridges, turning-bridges, stone or wooden immoveable bridges; as the draw-bridges are immediately joined, and make a part of the town-gates, we shall enter first into their construction.

They are generally ten feet wide, and twelve long; and are composed of the trunion-beam a, head-beam b, and six joists C, covered with two inch planks, d: The trunion-beam is 12 inches broad, and 10 thick; the head-beam 10 broad, and 8 thick, and the joists are five by six, tenanted into the trunion and head-

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beam; as these planks would soon wear out by the carriages that continually pass over them, they are covered with iron bars of seven feet long, and about three inches broad, one over each joint, and one upon the middle of the plank; their number is generally 32; each of these bars is fastened with four cramps, which are not represented here; the joists are likewise fastened underneath to the trunion and head-beams with iron plates each about 3 feet long: the trunions are about six inches long, three in diameter: fastened to the trunion-beam with two plates, one above and the other below, bolted and rivetted together; the rings or handles of the chains are joined to the head-beam

much in the same manner as the trunions.

Draw-bridges are drawn up and let down, by various contrivances; the most common way is, by a wooden frame, fuch as is joined to the draw-bridge in the third figure; it may be observed, that the side beams GK, HN, go tapering from the trunions E, F, towards the ends K, N, in order to make the frame EGHF, nearly of the same weight as the draw-bridge: It turns round the trunions E, F, upon iron plates, and the frame HG, moves in a cellar under the gate-way, built for that purpose; there are two holes, one on each side, to thrust two long poles, through upon the ends H, G, to press them down, and raise the draw-bridge, as likewife two chains are fixed to these ends, passing through the same holes, with a large ring at the end of each, whereby the bascul is drawn up, and the draw-bridge let down. This method can only be used when the ditch is dry; for when it is wet, the cellar is apt to fill with water, notwithstanding all the care that can be taken in the building of it; whereby the wood will rot in a short time, and the draw-bridge is in danger of not being drawn up when it is required; besides, the making this cellar in a proper manner, so as to be water-tight, will be very expensive.

Another method of drawing up draw bridges, and which is often practifed, is to make the bascul separate, and not joined to the bridge; fuch as is represented by the fecond figure: This frame is fixed by the trunions at L, P, over the gate-way, and two chains, fixed on the other ends M, Q, go each over two pullies or rather rollers, and are fastened with the other ends to the head B, D, of the draw-bridge BC, figure 1; fo that when the part MQ, is drawn down by chains fastened to them for that purpose, the draw-bridge raises. This method has the advantage, that in case the enemy should find means to break the chains which fasten the drawbridge to the frame, and thereby make it fall down, the frame M P, will also fall down and stop the passage, and it will not be in his power to raise it: But in case any thing should happen to the chains, an opening W is left in the middle of the frame, to pals through it, and this opening may be shut up by a wicket, that is to be lockt upon occasion. We have supposed this method to be used in the gate-way, represented in the thirteenth plate, where the fide view of the beam PQ is feen in the third figure, as well as one of the chains with its rollers.

It must be observed, that the head M Q of the frame must be well loaded with timber, in order to bring the frame nearly in equilibrio with the draw-bridge; which is not so easily done as one might imagine; and experience has shewn, that many engineers have miscarried in their design; and when this does not happen, the draw-bridge cannot be let down nor drawn up, without very great difficulty.

The only way of doing this, is to have timbers, or any other weights, fixed near the piece MQ, so as to slip off and on, and when both the bride and frame are fixed, to try how much weight w go.

Plate XV. Another way of fixing draw-bridges, is, a bascul with wings, such as is represented by the fourth figure, which is fixed over the gate-way, upon

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the two trunions E, F, and the chains are fastened to the ends of the wings; and two lesser ones to the ends A, C, of about eight feet long, with rings of 8 or 10 inches diameter, in order to draw down the hind part of the bascul, and thereby raise the bridge; and the bridge is let down, by raising up the hind part A C to the height of 5 or 6 feet, and then with poles they push it up higher, whilst others get upon the bridge to bring it down by their own weight.

When the bridge is down, two bolts fixed to it are pushed into two staples, drove into the fixed bridge; and to guard the sides of the bridge, that nothing may fall over, there are two strong chains fastened with one end to the wall, and the other to the post of the immoveable bridge, about four feet above the draw-

bridge.

It is easily perceived, that the bascul EC, must be of such a weight as that the bridge may be drawn up with a small force; for which reason, the frame is loaded with timber towards the hind part AC, in the manner represented here, in this figure; and it happens sometimes, that they are abliged to fasten shells or any other heavy weight at the ends A, C, to bring the weight of the bascul nearly equal to that of the draw-bridge.

This method of fixing draw-bridges has been in use a long while, and has been practised more than any other; but when it is used in the draw-bridge of the body of the place, the cavities cut into the front of the building, to receive the wings, disfigure the ornaments of that front very much; and another inconveniency it has, is, that every time the bridge is raised, it requires a great force at first to move it; this motion accelerates afterwards more and more, till at last it becomes so great, that it shakes the building very much.

But when draw-bridges are made to the outworks, or sometimes on the middle of a fixed bridge, this method is always used; then the bascul A D is support-

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ed by a wooden frame, of about 12 feet high, upon which the trunions E, F, turn: It is true, that when the bridge is drawn up, the wings are upright, and exceed the height of the bridge, by about 12 feet, which the besiegers endeavour to break by siring at them, and if they accomplish their design, the drawbridge falls down, whereby the passage is left open: But as no other method has yet been found, that answers the purpose better, this has been used to this day.

Mr. Belidor has proposed a new method of moving draw-bridges, in his Stience des Ingenieurs, that seems to be preferable to any other hitherto known: which is, instead of a bascul, he fixes two cylindrical weights to the chains, which move in a curve on each side of the passage, in such a manner, that the motion of the bridge is always uniform, provided these weights are properly adapted; so that without spoiling the front of the building, or shaking it, two men may move it up and down with the greatest ease.

Those young engineers, who are desirous of knowing how this curve is constructed, and the weights are applied, may consult that author.

Of fixed or immoveable BRIDGES.

Fixed or common bridges are either built with wood or stone, or sometimes with both; they are of various lengths, according as the ditch or river is less or more broad; they differ likewise in their breadth; for those built over the ditches of a fortress are seldom above 14 feet broad, which is sufficient for two carriages to pass in breast, though they never allow above one at a time: but bridges built over large rivers, are from 20 to 36 feet broad: That at Fulbam is 22 feet broad, and Westminster bridge 44, including the foot passages, and parapet walls.

When the bridge is to be built with stone, and the ditch is dry, the manner of laying the foundations of the

the piers, is the same as that of walls; it must only be observed, that as the piers support a great weight, the base of the soundation must be made large in proportion; and they are always piled, and have a wooden grate over them, unless the bottom be rocky, or otherwise very hard: But when the ditch is wet, two rows of dove-tail piles or planks, are drove round the soundation, at about 6 feet distance from it, and 4, 5, or 6 feet from each other; and the interval between these two rows of piles is rammed sull of clay, so as to keep the water out; or else, two rows of common piles are drove as before, of 3, 4, or 5, feet distant from each other, and to these piles are nailed boards at the inside, and then the interval is filled with rammed clay as before.

This being done, the water is pumped out, and the foundation funk, as before: This method will ferve in most cases, excepting in deep water, where the current is very great: As to the proportions of the piers, in regard to the width of the arches, and the length of the arch-stones, they will be given in the latter end

of this work.

If the bridge is made of wood, after the ditch has been funk to its proper depth, rows of piles are drove a-cross the length of the bridge, at 10 or 12 feet distant from one another; the length of these rows is equal to the breadth of the bridge; and 4, 5, or 6, piles in each of them; when they are drove in as far as they will Plate XV. go, the upper part is made level, and bearing beams laid over them, into which they are tenanted; over these the tie-beams are laid, and then the planks. The first figure represents the elevation of such a bridge, the second the plan, and the third the section.

The piles A, are a foot square, and the bearing beams B, 14 inches broad, and 15 or 16 high, and the tie-beams C, 8 inches broad, and 12 high; as to the binding joists D, they are about 8 inches high,

and 6 broad; the planks are 4 inches thick; the posts E about 4 by 6 inches, the top-rails d, about the same dimensions; the middle rails e, and struts f, are some-

what less than the former.

The bearing-beams B, are ten feet from each other, and supported by five piles each, and often with more, that is, when the bridge is very high: These piles should open below, as is represented in the section, figure 3; but it is easier to drive them vertically, as they are generally in that position; but since Mr. Vaulvois's new invented machine, they are as easily drove obliquely as upright; we choose this position, as making the bridge stronger and firm: If the soundation is hard and stony, the piles are shod with iron: The abuttments of all bridges are always made of stone, because the sirmness and strength of the bridge depend

very much thereon.

When a bridge is made over a navigable river, the middle opening between the piles is made wider than the rest, in order that the boats and small craft may pass through; and to prevent them from running foul on the piles, two or three planks are nailed on them, a little above the furface of the water. When the current is pretty rapid, it is necessary to add breakers; that is, two rows of piles are drove within five or fix feet of each other, and two piles in the center line between them, at about fix or eight feet distance from the bridge, so as to present a point on each side; these piles are braced to the others with timbers of about 4 by 5 inches, in two or three places; there are also boards nailed to them, in the fame manner as we have mentioned before. This is the way that Fulham bridge was built; but those over the ditches of a fortress require no fuch precautions.

As the piles of wooden bridges are liable to rot very foon, in ditches which are sometimes wet, and at others dry; the best way to make the work durable, is to lay a foundation of masonry under them, as high as the

the highest water, upon which strong beams are laid, into which the piles are fixed with tenants; this will make the bridge last much longer, and thereby the often repairing is avoided, which is not only expensive, but likewise very inconvenient in stopping the pas-

fage out and in of the place.

To prevent the carriages from destroying the planks, fand and gravel is laid over them, of about a foot or more deep; and very often they are paved, especially those of fortified places; the gravel or pavement is made higher in the middle than at the ends, that the rain water may run off freely, and not rot the wood: This may be seen in the third figure, as likewise in the second; where one part represents the gravel or pavement, and the others, the planks and the binding joists.

Some engineers drive the thickest part of the piles foremost, and, on the contrary, others the smallest; the reason the former give for their practice, is, they say, that timber should be used in the position they grow, whereby they will last longer; because the fibres or grain of the wood are as it were adapted by nature to that position; whereas the latter affirm, on the contrary, and I think, with good reason, that being, placed so, the wet will enter more easily in those parts, where the branches have been cut off, and of consequence, the wood will sooner decay: but if they are in a contrary position, the water will run off, without being able to enter through the pores of the wood.

As our defign is not to give a compleat treatise on bridges, but only so much as is necessary for a young engineer to know, and what most commonly happens in practice; we shall enter no farther into the manner of making all forts of wood bridges, either with a single arch, or with a great many; neither shall we say any thing of turning or slying bridges, as being uncommon in this country; we shall add only something relating to bridges of communication from one work to

another;

another; as relating more immediately to an engineer's business.

As the besiegers endeavour always to destroy these bridges if possible, either with fire, shells, or shot; in order to hinder the troops in the outworks from being relieved or succoured by the garrison, and to obstruct their retiring, when hard pressed: To prevent this, these bridges are made as low as is possible, that is, they are made even with the surface of the water, and sometimes a foot under it; and, to save expences, piles are drove in the manner mentioned above, opposite to each other, and covered with a tie-beam; this is repeated at every ten or twelve feet distance, quite cross the ditch, like so many trusses; over which planks are laid, when there is occasion to pass over, and not before; at all other times these planks are kept in store-houses.

When there is a fufficient depth of water, a good number of boats are also kept to pass from the curtain to the ravelin, in case the bridges should fail: those that go from the ravelins to a counterguard, lunet, tenaillon, or into the covert-way, are always placed near the extremity of the faces, where a part of the parapet it cut off, to pass by, or else a passage is made through it for that purpose.

S E C T. XVI.

Of BARRIERS, GATES, and PORTCULISSES.

Plate XV. THE fifth figure in this plate reprefents a barrier-gate, such as are made in the covert-way, at the entrance of a town, or in the passages cut in the places of arms, through the glacis; which is about 14 or 15 feet wide, and 10 feet high: the two side-posts are from 10 to 12 inches square, the part which is sunk into the ground is lest rough, and about

Part III.

about fix feet long; the futle is as broad as the posts are thick, and about six inches high: the frames of the gates are from 5 or 6 inches square, and the planks 6 inches thick. These gates are locked by an iron bar, turning about a bolt, so as that when one end raises, the other turns down, and one end is catched by an iron hook, whilst the other is sastened with a

padlock.

The fourth figure in plate XIV. represents a gate made under the covered gate way; each side turns upon a strong iron pivot, standing on an iron socket, and are fastened above to the wall, with hooks and hinges, much in the usual manner of common doors; the outside is covered with iron bars, in the manner represented here, for about eight feet high, and the parts between the bars are drove sull of diamond headed nails, to prevent their being cut open: In one of these gates, is made a wicket, in order to pass through, when there is any danger of surprize, and in the morning before the party of men, that is sent out to reconnoitre and see whether any enemy appears, is returned; the upper part of the gate is lest plain, without any iron, because there is no danger of cutting it there.

The fifth figure of this plate represents a harrow or port-culiss, which is drawn up by means of two-chains fixed to the upper ends A and B, and the other ends are fastened to a wooden roller, with a handle on each side, which, when turned round, the chains roll upon it, and lift up the gate, and are fastened above, by two strong bolts: the lower cross bar is covered with an iron flat bar from one end to the other, as likewise the rails or uprights as high as a man can reach, to prevent

its being cut open.

These portculisses are, in my opinion, better than those called organs, because if an enemy should come so near as to cut it open, it will not be so easily done, if they are well covered with iron; and the men behind them may fire through it with very little danger; whereas,

whereas, the enemy must be very much exposed to their fire: besides, there might be an opening left above, to throw stones and blocks of wood upon those that dare approach them.

S E C T. XVII.

Of SENTRY-BOXES and NECESSARY-Houses.

ORMERLY fentry-boxes were made of hewn stones, and placed on the falient angles of the bastions, ravelins, and other outworks, and fixed to the walls; as they may be feen in most fortified towns in France, with a flower de luce at the top of them: but it has been found by experience that they ferve as marks for the beliegers to direct their approaches by, for which reason, they build no more in this manner: the prefent method is to make them of wood, and fo as to be moved from one place to another; and they are mostly placed at present upon the middle of the parapets of the faces; and wooden steps are made to get up, or flopes are sometimes cut into the parapet for that purpose; by which the enemy has it not in his power to make any advantage of their fight; these wooden ones are, besides, less expensive, and answer the intent full as well, which ought always to be confidered in every kind of work whatfoever.

Plate XV. The figure given to fentry-boxes is either pentagonal or square; we make it a pentagon, as may be seen in the plan, figure 6, and the elevation, figure 7, as being more convenient, for by turning the point outwards, the adjacent parts are better discovered from the sides next to that angle: the sides are about four feet long, and six feet high; the timbers of the base ought to project about a foot each way, so as to have a good base to stand upon, to prevent the

wind

wind from blowing it down; and if this base is not sufficient, it may be pinned down by stakes: In each side is a hole to look out, of 4 inches broad, and 8 high: as the plan and elevation of this sentry-box is

fo plain, there requires no further explanation.

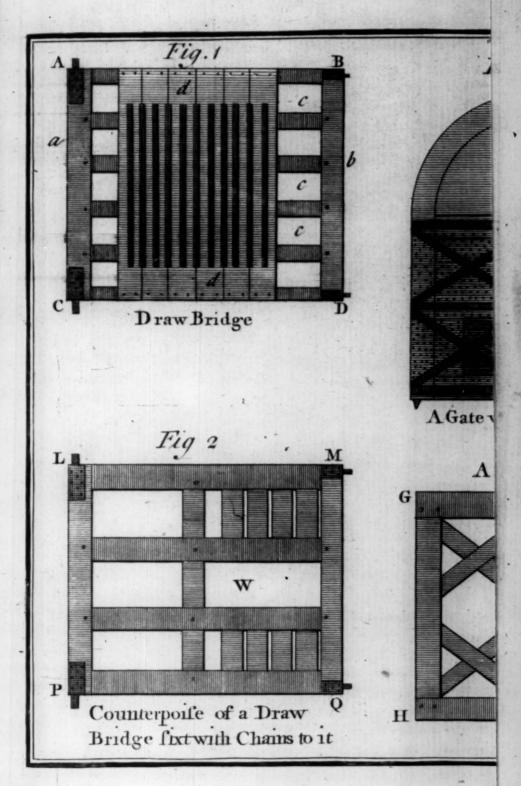
The fentry-boxes placed near the governor's house, powder-magazine, houses, &c. are made of a square form, because the fentry has but one or two places to observe: each side of the base is four feet, and the box six high, besides the covert: and they are made so light as to be easily turned about, or carried from one place to another.

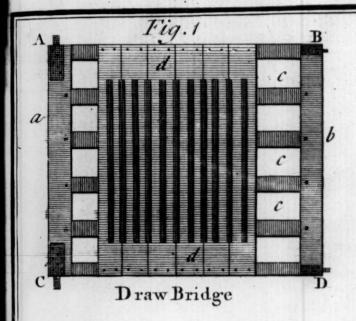
Public boghouses fall likewise under the care of the engineer: They ought to be placed over rivers, or standing water, if it can be done, to prevent, if possible, the stench from becoming nauseous; but where this cannot be done, they are placed on the curtain, where a passage is cut through the parapet, and supported with braces against the wall, so as to hang over the ditch; but care must be taken, not to place them too near the sally-ports, otherwise, they will make the passage disagreeable. But, in my opinion, if they were placed at the slope of the rampart, over the common sewers, it would be much better, because the rain and other waters of the streets would carry off all the nastiness, which makes them so disagreeable.

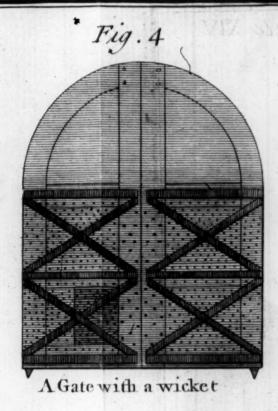
S E C T. XVIII.

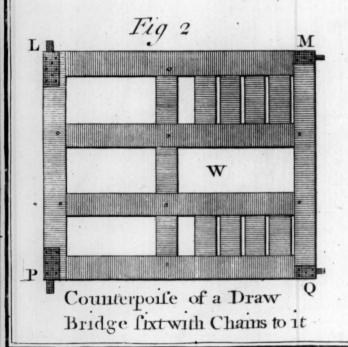
Distribution of HOUSES and STREETS.

TOWNS were formerly built any how, according to the builder's fancy, without the least regard to regularity or beauty; but now-a-day, when a place is sortified, which is not occupied by any houses or other buildings, great care is taken, to make every









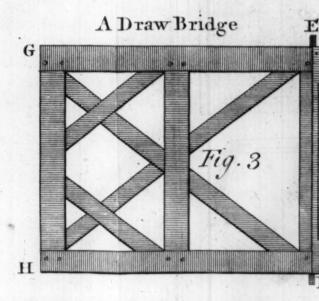
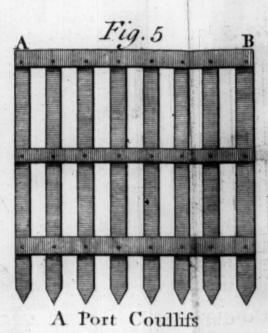
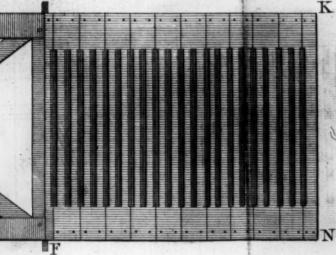


Plate XIV



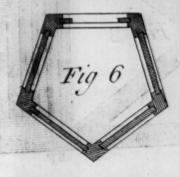
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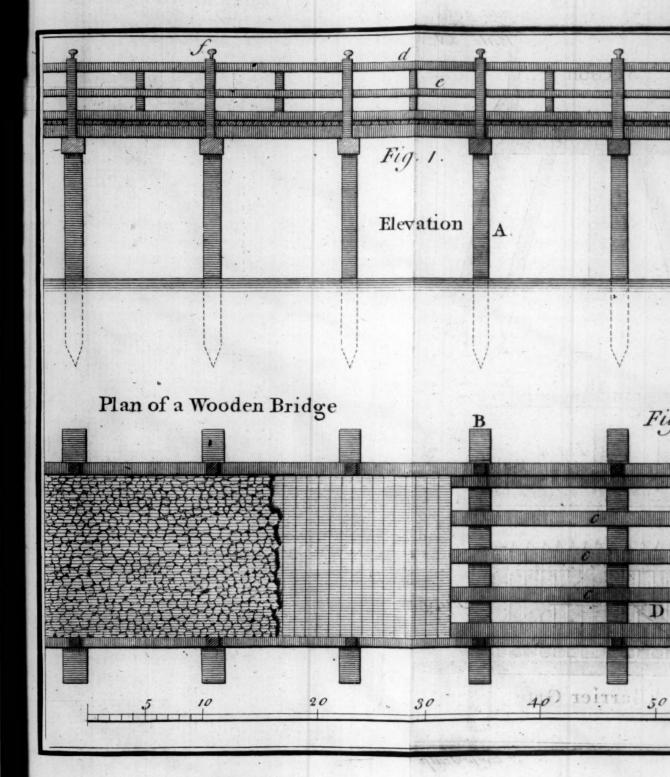


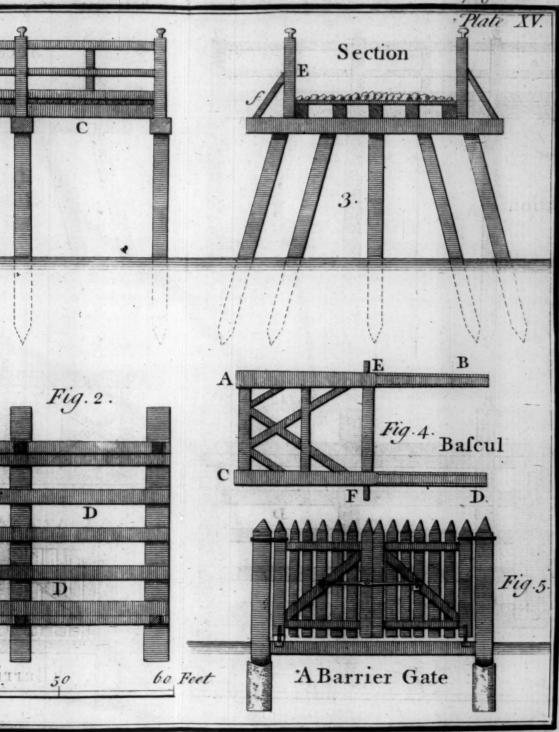
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Fig. 7

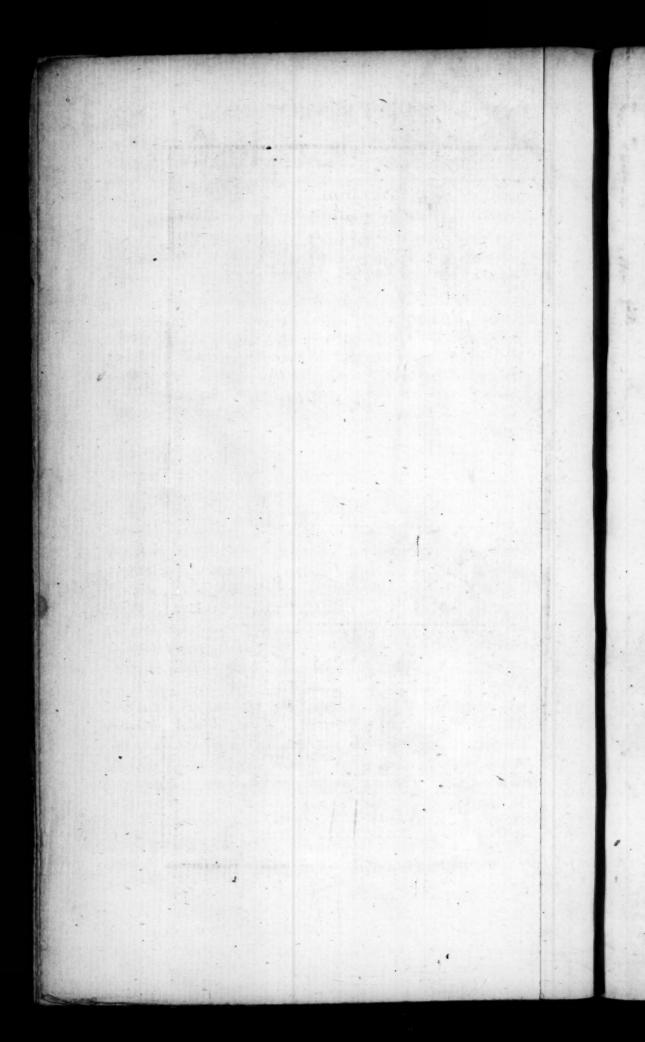








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part within as regular as is possible; for which reason, care is taken to make the ground level, at equal distances from the center of the place, and descending gradually from that point in an easy slope towards the ramparts; that the waters in the street may run into the ditch.

Some German engineers will have the streets to part from the center of the place, and directed to the middle of the bastions and curtains, pretending that thereby, the troops assembled upon the parade, may render themselves in a shorter time to any part of the rampart, where their presence is required; this might be well for the desence; but then all the houses, and other buildings are made with a bevil, which is so great an inconveniency, that I believe, this, method will never

be put in practice.

It is not only the regularity of the streets, which is fufficient, but likewise the rightly placing all the military buildings, fuch as the governor's house, guardhouses, store-houses, and magazines of different kinds: The governor's house is aptly placed in the middle of the fide of the great square, opposite to the great church, fo that he may fee the troops, parade, and the garrifon under arms, from his windows, or gallery; there should likewise be a guard-room in that square, from which the fentries placed at the governor's door, and near the magazine are taken. The other guard-rooms are placed near the gates, and fometimes one near the barracks: The store houses and magazines are best near the ramparts, where they are at hand in case of siege: As to the powder-magazines, they are always placed in the gorges of the bastions. In places near the iea, or navigable rivers, the naval store-houses must be as near the harbour, where the ships lie, as possible; on the contrary, those for land service on the opposite, or land fide; as we have mentioned in the first book of fortification, where we have given the construction of those places. When

When a town is very large, and therefore much room to build upon, it is necessary, for the publick use, to make feveral squares; but on the contrary, if the place is but little, and no room to spare, there must at least be one, in the center of the place, whose bigness ought to be in proportion to the extent of the fortification, and consequently, to the number of troops required to defend it: For this square not only serves as a market place, but likewife, to draw up the troops and parade on it. Mr. Belidor thinks, that a fortress of fix bactions, whose exterior side is 180 fathoms, should have a square, whose side is from 40 to 45 fathoms, a place of feven bastions, one whose side is from 55 to 60; that of 8 bastions, from 70 to 75; that of 9 or 10 bastions, from 80 to 85; and lastly, that of 11 or 12 bastions, from 90 to 95 fathoms; however, he fays, that the engineer employed in these works will be able to judge of the proper bigness which these squares ought to have.

There is commonly an open space left at the entrance or every gate of the town, in order that the guard-house, which is made there, may have room before it, to draw up the guard, and, in case of danger, to defend the gate and adjacent places: besides, these openings have a good appearance, and ferve also for the carriages to get out of the way, when any others

are coming in.

In regard to the streets, the principal ones should go from the great or principal square in the center, directly to the town-gates; to the ramparts, and to the citadel or harbour, if there is any; in order to be enfiladed by the guns and troops, placed in that square in case of any danger or surprize: It must be observed, that the cross streets are all parallel to one another, and perpendicular to the former; fo that all the buildings be at right angles to each other.

The principal streets are generally 36 feet wide, in order that three carriages may pass a-breast at a time, or if two of them should stop, another may pass by, as likewise room for the foot passengers; but in regard to the other streets, they need not be so large; if they are from 18 to 24 feet wide, it will be sufficient, because there pass seldom above one or two

carriages at a time.

The distance between one street to that which is parallel to it, is various; Mr. Vauban made them only the breadth of three houses, at New Brisac; that is, but one between the two corner houses; which, in my opinion, is not sufficient, because there is scarcely any room lest behind to build warehouses, or shops for workmen, which are absolutely necessary; neither is there any room for gardens or openings for the light and air to pass freely, both useful for the preservation of the inhabitants.

We suppose that each house takes up 36 feet in the front, and the interval between the parallel streets is equal to the breadth of four houses, or 144 feet; so that if the houses are 36 feet deep, each of them will have an opening behind of the same extent, excepting the corner houses; either for a garden, or to build shops or store-houses: we suppose that the shops to work in are all behind, and in the front only those to expose and sell the goods.

Plate XVI. We made but one square in this design, whose sides are 75 fathoms, but if it should be thought necessary to make more, one of the spots occupied by houses terminated by sour streets, in the most convenient place, may be used for that purpose; and it is there where the market for dry goods may be kept, and a •

town house should be built.

The governor's house is supposed to be in the great square, marked by the letter B, and the great church opposite to it, marked C: the governor's house takes up as much room as three others, and his garden as much as two: so that the house is 108 feet in front, and 36 in depth, and the garden 36 feet broad, and

72 long: and if this is not thought sufficient, the whole

opening behind may be taken into his garden.

It is also common to build a fountain in the very center of the place, or great square, decorated in a neat manner, with four spouts facing the four principal streets: For since water is the most necessary thing wanting in a garrison, both for men and cattle; there cannot be too much care taken to supply the place with it: for which reason, water is brought from springs, or rivers near hand, by means of pipes, and engines if necessary, at the same time that the town is built; there ought besides this, in the center of the place, to be several others contrived, in the corner of the streets, if the place is large, to supply every part of the town plentifully.

When an old place is fortified where there are houses, the streets are left as they were; the principal ones are only widened and made strait if possible, either by demolishing the old houses, and building new ones, or else waiting till the old ones decay, and then obliging the inhabitants to build them on a strait line: this is often practised by the French, when they fortify old towns, as I have seen at Douay, and other places: it is true, that this is against the laws of England; but any thing that tends to the benefit of the public in general, ought to be preferred before the obstinacy of private

people who lofe nothing by it.

In new places built abroad, in plantations where there is sufficient room, and where the fortification often consists of the town-wall and ditch only; I would make the intervals between the streets greater than what we have represented here in this plan, as likewise all the bye streets about 30 feet wide: For nothing contributes more to the wholesomness of the place, as well as agreeableness, than fine large streets, and great openings behind the houses, planted with trees, especially in warm climates; besides, all the shops to work in should be built there, and no others ought to be per-

mitted

mitted in the front of the streets, than those for selling

goods, as we have observed before.

The engineer employed in the building of Halifax, in Nova Scotia, has, in my opinion, committed a great mistake, in building the streets so near to each other as he did; for each house is 36 feet in front, and 72 in depth, and no opening is left behind, as I have been informed, by an officer that was there, and employed in the works. This mistake can arise from no other reason, than the manner of building fortified places in Europe: but the case is quite different, because these places have a great number of outworks, besides the body of the place; for which reason, we are obliged to crowd the buildings as much as we can, that there may be room for the inhabitants, besides a large garrison: whereas abroad, where the fortification is confiderable, the place should be made as pleasant and convenient as possible.

It was faid, the few people that went there, were not fufficient to clear a larger spot of ground; but in answer to this, I say, they need not clear more ground at first than to build upon; and leave the openings behind for another opportunity, when they have more time; by doing this, the wood left may serve for timber to build out-houses, and the branches for fewel to burn, when perhaps they must go far for it, and are exposed to the insults of the Indians at the same time.

The store houses for amunition and artillery being military edifices, and requiring much room, it is not easy to determine their situations, because they depend on many circumstances, which cannot so well be known as upon the spot; it is necessary to observe, that they should be separate from one another, as well as from other buildings, to prevent accidents as much as is possible, which may happen by setting the adjacent buildings on sire, either by chance, or by the contrivance of an enemy: When there is a brook or river that passes through the town, it is requisite, for the good

of the service, that the store-houses should be near it; to bring timber and other materials, as well as stores,

by means of water carriages.

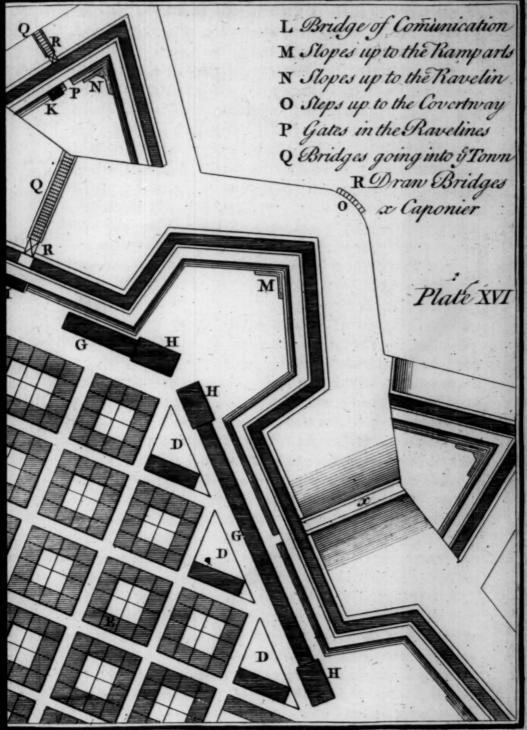
We placed the store-houses and magazines here, near the curtains, which have no town gates; such as are marked D; because they are not near at hand, to transport them upon the rampart, where they are wanted in case of a siege: and the triangular openings formed by the streets may serve them as yards, which should be walled in; they are likewise near the barracks, which is another conveniency; for as soldiers are commonly employed in ranging and moving them, they are near at hand upon all occasions.

The barracks are generally placed near the rampart of the curtains, as marked here by the letter G; with pavillions H at the ends, which are designed for the officers lodgments; this is undoubtedly the properest place for them; because an open space may be lest before them to draw up and exercise the troops; the detachments in time of war may be more privately made for any enterprize that might be thought necessary, which could not so well be done in any other place; and the troops are quite separated from the inhabitants, with

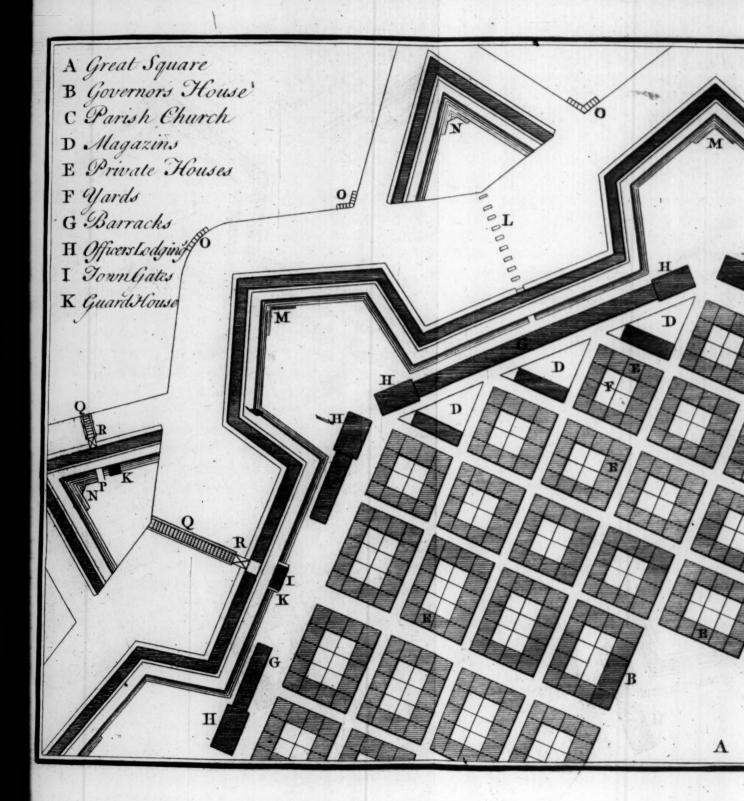
whom they do not always agree.

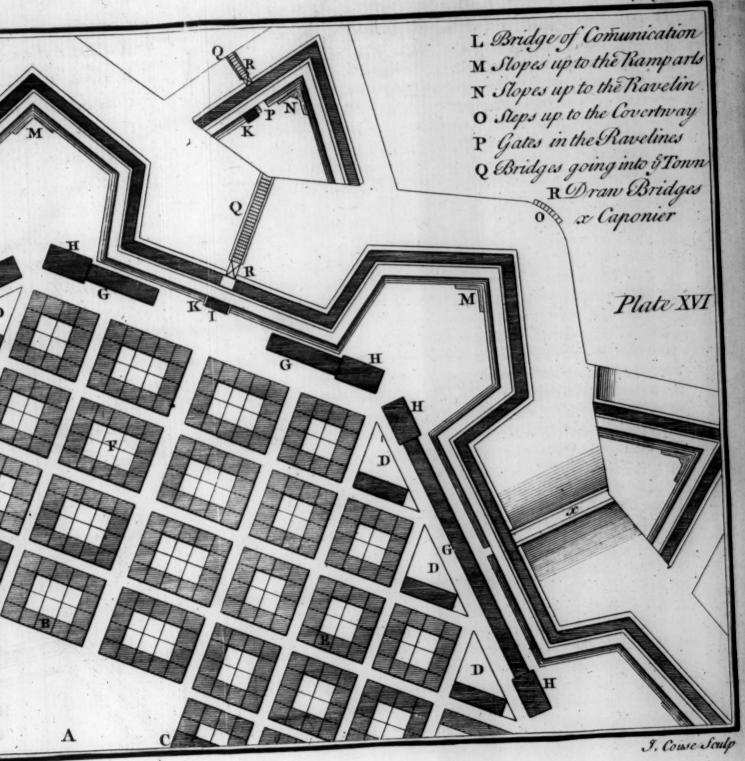
As the tap-houses and bake-houses, for ammunition-bread, are necessary for the subsistance of the garrison, they ought to be built near the barracks, and so as to have a guard-room not far from them, in order to prevent any riotous proceedings, that might happen; and as to the hospital, it is almost needless to mention, that it should be placed in some bye place or other; so as to be separate from the inhabitants, and noise of the workmen; especially near a brook or river, in case there is any that passes through the town.

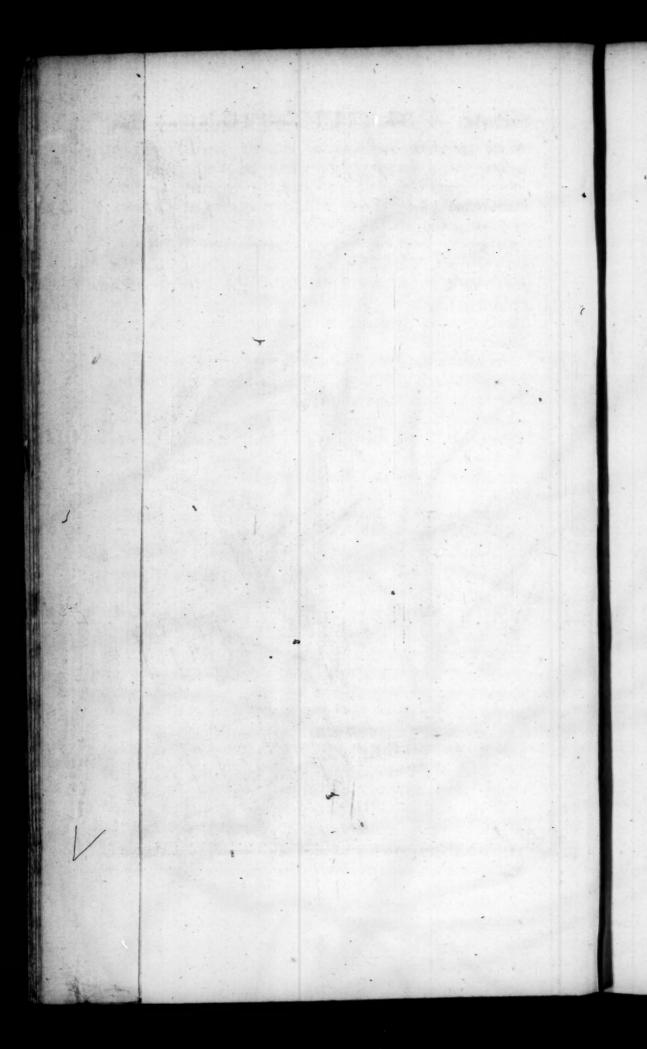
This is nearly all that can be faid in regard to this fubject, when the place is large; but in small forts there requires not so many store-houses, which however are always placed near the rampart. In such places,



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where there are harbours or citadels, regard must be had to them in the placing these buildings; but the subject being so plain and easy, it requires no farther explanation; since a little practice and common sense will suggest the necessity of placing these buildings in the most convenient manner: but the execution of these, and all other military buildings, requires much more capacity and knowledge, in order to make them solid, and at the same time convenient; which we shall discuss more particularly, by treating of them each separately.

We have omitted several other things too trifling to be mentioned, which the reader will partly see in the fixteenth plate, which besides will serve as a further illustration to what has been mentioned; and what remains to be done, we must leave the sagacious reader to find out himself, the subject being too copious to treat

particularly of all the minute parts.

SECT. XIX.

Of POWDER-MAGAZINES.

RORMERLY powder-magazines were made in a quite different manner from those at present; they placed the powder in towers that had been built in the town-walls, by which they became liable to many accidents; for when the powder happened to be set on fire, either by chance or by some concerted scheme of the enemy with the inhabitants, it opened the town, and made a breach for the enemy to enter, as it happened at Aire, according to Mr. Belidor, when that place belonged to the Spaniards: The French, who then besieged it, having got intelligence from some inhabitant, sound means to set the powder on fire, that was placed in one of the bastions; which had so great an effect, as to make a large breach, and as soon as the besiegers had prepared

for an affault, the garrison furrendered, whereas, without this accident, they might have defended themselves

much longer.

Finding by experience, that the building magazines in the rampart was of dangerous consequence, they are now placed in different parts of the town, and made of various figures; but it was a great while before the right one was found: the most common had several pillars in the middle to support the arches; but to bring these double arches under the same roof, the top must be loaded with fo great a quantity of masonry as almost burst the arches: finding this method inconvenient, it was agreed to make them of one fingle arch, as being much better than the former: the form of this arch was of the Gothic kind; and in order to get more room for lodging the powder, a floor was made at the spring

Plate XVII. But Mr. Vauban having observed, in feveral fieges, that these kind of arches were too weak, and that the floor loaded the piers very much to no purpose, fince prudence requires not to lodge so much powder in the same place; and being better to divide it into feveral parts, he absolutely rejected all the different methods till then followed, and proposed a new one, much more perfect; and which is that represented by the first and second figures, and is the only one hitherto executed with fuccess; though something may be changed for the better, as we shall shew hereafter.

If we may believe what has been faid on that subject, we are told, that there were thrown upwards of 80 shells upon a magazine of this fort, at Landaw, with out doing the least damage to the vault : the same thing is reported to have happened at Ath, and in feveral other places. Mr. Demus, director of fortification, and a person of good reputation, assures, that in the fiege of Tournay, by the duke of Malborough, where he ferved, there were thrown upwards of 45000 shells into the citadel, and the greatest part of them sell upon two powder-magazines of this sort, and yet neither of them was damaged; whereas there were some built with Gotbic arches, that were destroyed by three or sour shells that sell upon them, notwithstanding that they had been covered with sive or six seet of earth, some time

berore the siege began.

The dimensions of Mr. Vauban's magazines are as follow; the plan is 60 feet long, clear within, and 25 broad; the foundations are 9 or 10 feet thick under the long sides which support the arch; and these sides he made 8 or 9 feet thick, according as the masonry was good or indifferent, and 8 feet high from the foundation to the spring of the arch; so that, making the sloor about two feet from the ground to keep it free from all dampness, there remained 6 feet for the height of the story.

The thinnest part or hanches of the arch is three feet thick, and the arch made of four lesser ones, one over the other, and the outside of the whole terminated in a slope to form the roof; from the highest part of the arch to the ridges is 8 feet, which makes the angle somewhat greater than 90 degrees; the two wings, or gable ends, are four feet thick, raised somewhat higher than the roof, as is customary in other buildings; as to their foundations they are 5 feet thick, and as deep as

the nature of the ground required.

The piers or long sides are supported by sour counterforts, each of six seet broad, and 4 seet long, and their interval 12 seet; between the intervals of the counterforts, are air holes, in order to keep the magazine dry and free from dampness; the dices of these air-holes are commonly a foot and a half every way, and the vacant space round them are three inches, made so as the in and outsides be in the same direction, as may be seen by the plan; the dices serve to prevent an enemy from throwing sire in, to burn the magazine, and for a surther precaution, it is necessary to stop these

these air holes with several iron plates, that have small holes in them like a skimmer, otherwise fire might be tied to the tail of a small animal, and so drive it in that way; this would be no hard matter to do, fince where this precaution has been neglected, egg-shells have been found within, that have been carried there by weafles.

To keep the floor from dampness, beams are laid long-ways, and to prevent these beams from being foon rotten, large stones are laid under them; these beams are 8 or o inches square, or rather 10 high and 8 broad, which is better, and 18 inches diftant from each other; their interval is filled with dry fea coals, or chips of dry flones; then over these beams are others laid cross-ways, of 4 inches broad, and 5 high, which are covered with two inch planks.

To give light to the magazine, a window is made in each wing, which are shut up by two shutters of:2 or 3 inches thick, one within and the other without; that which is on the outfide is covered with an iron plate, and is fastened with bolts, as well as that on the inside. These windows are made very high, for fear of accidents, and are opened by means of a ladder, to give air to the

magazine in fine dry weather.

There is likewife a double door made of strong planks, the one opens on the outfide, and the other within; the outfide one is also covered with an iron plate, and both are locked by a ftrong double lock; the ftore-keeper has the key of the outfide, and the governor that of the infide: the door ought to face the fouth nearly if possible; in order to render the magazine as light as can be, and that the wind blowing in may be dry and warm. Sometimes a wall of 10 feet high is built round the magazine about 12 diffant from ir, to prevent any thing from approaching it without being feen.

Here we take not so much precautions, for I never did fee any with double doors, or shutters, and they

matter to destroy them. I have seen a project for mending a powder-magazine at Minorca; there were to be no less than four doors, and as many windows as are commonly made in a dwelling house: there was to be likewise a brick floor, and to render the work compleat, cross-walls were to be built within, at every twelve feet distant: and yet this project was contrived by a person of the greatest repute for his skill in engineering; and would, in all probability, have been executed, had I not prevailed with the surveyor general at that time to lay it aside.

Such a magazine as this will hold about 200 000 pounds of powder, when the barrels are fix above one another, which however is not done, but in case of necessity, because when they lie so much on each other, it is very trouble some to remove them, and change their position, which ought to be done once a year at least; otherwise the salt petre, being the heaviest ingredient, will descend into the lower part of the barrel, and the powder above will lose much of its goodness; but to prevent the barrels from rolling, when some are taken off, two wooden posts are erected, of about 4 or 5 inches square, between every 10 or 12 barrels, by this means they may be piled up as high as you please, or taken off without any danger.

Mr. Belidor would have brick walls made under the floor, instead of beams, and a double floor laid on the cross-beams; which does not appear to me to be so well as the manner proposed here; the reader is, however,

at liberty to chuse that method he likes best.

Instead of making the side walls 8 feet thick, as Mr. Vauban does, we have made ours here but seven, and turned the counterforts contrary to his position; that is, instead of being 6 feet broad, and 4 long, ours are 6 feet long, and 4 broad, which strengthen the walls very much; as his were only 12 feet distant from each other, ours become 14 feet asunder, supposing the

extreme

extreme ones to be within a foot from the infide of the

wings produced.

It is likewise to be observed, that instead of making four arches one over another, each of them the length of a brick thick, in the manner of Mr. Vauban, we make but one continued arch three feet thick, which makes it much stronger, as it easily might be proved by what has been demonstrated in the second section. The reason of making our side walls seven feet thick only, instead of eight, according to Mr. Vauban, is because we found, by the rules of mechanics, and the strictest computation, but 7 feet and two inches, when they are four feet long, and fix broad: but by making them fix feet long, and four broad, the walls are capable of a greater resistance than his, and they being found ftrong enough by a long course of experience, there cannot be the least doubt, but that ours will be fufficiently strong.

In the theory of arches we made no allowance for friction, but consider the stones only according to their weight, whereas, in that of the walls which support earth, we made an allowance of one third of the weight, for the friction, and yet our walls are as strong as those built by Mr. Vauban; it may feem contradictory to make no allowance here; but if it be confidered, that the stones never close and bed so together as to make one continued folid, as the theory supposes; but on the contrary, lay often hollow, and the void spaces are filled up with bad mortar, it is a great while before these piers or walls are dry, and become capable of as much resistance as is required: besides, an allowance must be made to resist the force of the shells thrown upon them, as has been observed in the second

fection.

In order to succeed in these kind of buildings, it is highly requifite that the engineer should watch the workmen continually, in order to make the wall as folid and compact as possible, that the stones or bricks bed well, and no holes big-enough to hold a stone or brick to be filled with mortar: And lassly, to make use of the best materials to be had thereabouts; and when the arch is built, the centers should be left to support them, at least for six months, that is, till the work is settled and dry, otherwise the arch is in danger of tumbling down, or else the walls must be made stronger than

they need to be.

The third and fourth figures represent the plan and section of a large magazine, for stowing a great quantity in the same place: the piers or side-walls, which support the arch, are here so feet thick, 72 feet long, and 25 high, from the soundation to the spring of the arch; the middle wall, which supports the two small arches of the ground floor, is 8 feet high, and 18 inches thick, as are likewise the arches; the thickness of the great arch is 3 feet 6 inches, and the counterforts, as well as the

air-holes, are the fame as in the former.

Such large magazines as this, are by no means to be built in fortified towns, because if any accident should happen, all the powder would be lost at once, whereby the place would be obliged to capitulate; but in some inland part of the country near the capital, where no enemy is expected, they might be used, as for a general magazine, and that from thence the powder might be distributed to the several places where it may be wanted: yet, in my opinion, it would be better to make two small ones, and place them at a proper distance, that if one should be blown up by accident, the other might be safe.

The ridge of the roof makes a right angle in both these magazines, and it is necessary to observe, that as the soundations grow deeper, so they ought to increase in width; this is obvious from the common practice of making walls thicker as they increase in height; but no certain rule has hitherto been given, to know how much that increase is to be; supposing the soundation to project inwards, by six inches only, which

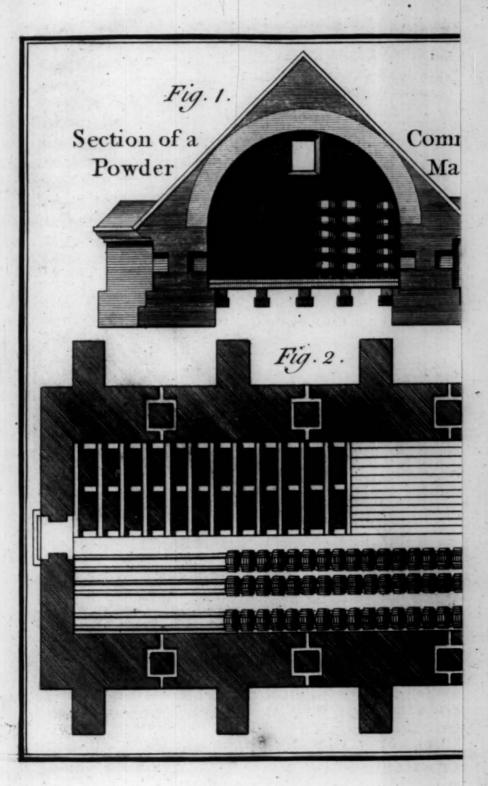
which feems to be sufficient, since the walls never fall that way: then I would allow six inches for every foot and a half depth on the outside, so that if the soundation be six teet deep, its breadth must be increased by two feet divided into sour steps; by this means you may know at all times how broad a soundation must be, when its depth is known. Although this rule is not founded upon a demonstration, yet, by the observations of common practice, it appears to be sufficiently accurate upon all occasions.

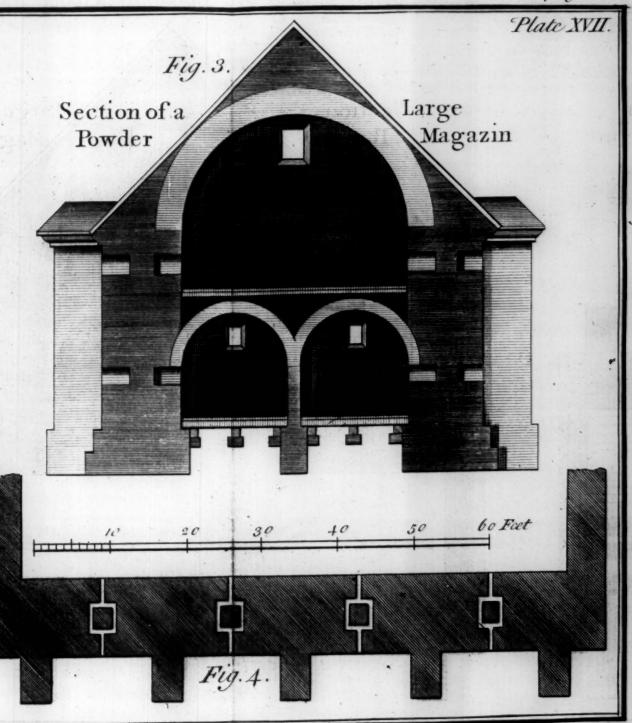
SECT. XX.

Of BARRACKS, HOSPITALS, and STORE-

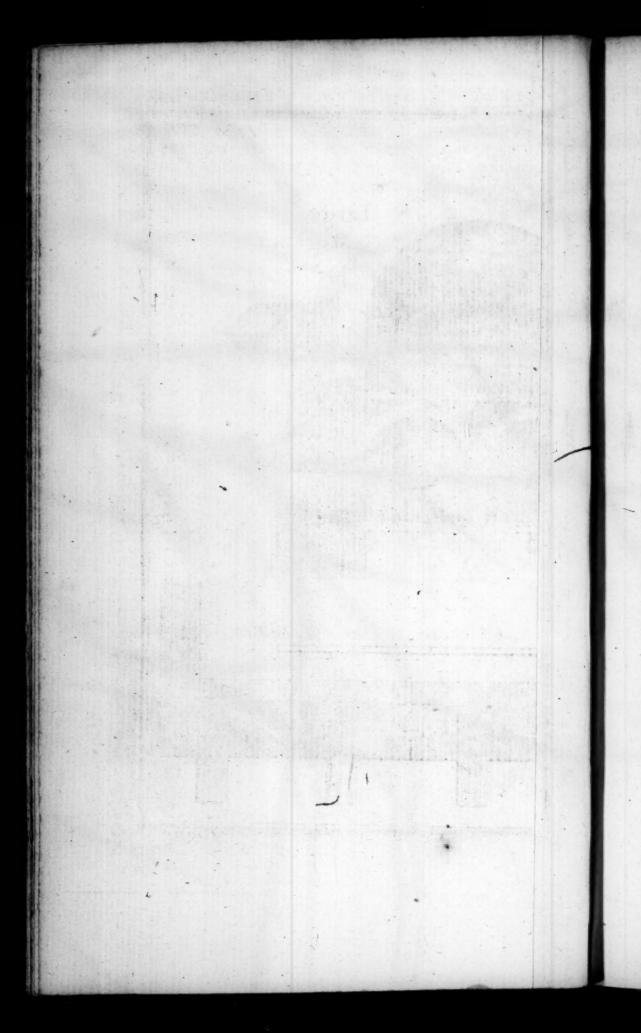
Plate XVIII. DARRACKS are built now-a-day in all fortified places, to keep up the discipline, and good order in the garrison: they have been found fo useful, that no place is built without them; and experience shews, that those garrisons which have them, are much more quiet, on account of the conveniency which non-commissioned officers have to visit the quarters every evening, and to see the foldiers flut up their quarters, which cannot be done when they are lodged amongst the inhabitants, where they have the liberty of going out and in whenever they please; besides, when the governor has a mind to make a detachment, or fend out a party, he cannot do it, without the knowledge of the whole town: If any alarm happens, the garrison cannot be assembled without great trouble and lofs of time; whereas, when there are barracks, every thing necessary for the good of the service may be done with eafe.

Barracks are built different ways, according to their different fituations. When there is sufficient room to make a large square, surrounded with buildings, they





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are very convenient, because the soldiers are easily confined to their quarters, and the rooms being contiguous, any order may be executed with privacy and expedition, and the soldiers have not the least connexion with the inhabitants of the place, which prevents quarrels and riots.

This disposition of the barracks is especially convenient for the horse and dragroons, because they want a convenient place for the daily mounting their horses; and in this case, the lodging-rooms are built over the stables, with a gallery serving for a communication from one room to another, quite round the building, with staircases in the corners, and sometimes another in the middle of each front; but care must be taken, to make the first row of lodging rooms pretty high, or else they will be darkened by the gallery above them.

When the barracks are built near the ramparts of the curtains, as Mr. Vauban has done in almost every place he fortified, they are composed of a large pile of building in a strait line, for lodging the soldiers, with pavillions at the extremities for the officers: these barracks are generally two or three stories high, besides the

ground floor.

Between every two rooms in the front, is an entry of 8 feet wide, with doors to the four contiguous rooms, and a stair case leading to the upper stories; as to the bigness of the rooms, Mr. Vauban made them 22 feet long, and 18 broad, in order to hold four beds each; I have seen some large enough to hold six beds, and with two chimneys in them; there were three men to each bed, which is the custom in all the French garrisons, because it is supposed, that one of the three is always upon duty, so that there is never but two in one bed at a time.

Our barracks here, at Woolwich, are but 16 feet each way, with three beds in each room, to hold fix foldiers only, which is not sufficient, because it requires too large a building to quarter a whole regiment in

them. The plan and elevation in the eighth plate is much in the fame manner, only we suppose four beds in a room, which they may hold; the rooms are 16 feet each way, though I think that if they were 20 feet long, and 18 broad, it would be much better; the ground story is 11 feet high, the next to it 10, and the last but 8.

The outfide wall is two feet thick, and the partition or cross wall a brick and a half; for if these latter are thinner, every thing that is done, and faid, will be heard by those in the adjoining rooms: the outward doors are a feet and a half wide, and 7 high; the inner ones 3 feet wide, and 6 and a half high; the windows are 3 feet wide, and 6 high in the ground floor, the upper ones have the same breadth, but their height diminishes in proportion to the height of the story; that is, the second row is 5 feet high, and the last but 4: the chimneys are 4 feet wide, and 18 inches deep, going partly into the wall, and projecting partly in the

The corner houses, being designed for officers lodgings, have each an entry of 6 feet wide, with a staircase and a closet of 5 by 6 feet at the further end: under the stair-case is another going down into the kitcken and cellars, which we suppose are built under the officers houses; but in regard to the soldiers barracks, there is no occasion to make either kitchen or cellar, as they have done at Woolwich.

The third figure in this plate represents the section of the elevation, where it may be feen that the stair-case goes strait up from one floor to the other; but if this is found inconvenient, it may turn at half-way, with a landing-place: the roof is divided into two ridges, because it is both customary, and more convenient, than if it was continued, which would make it too high, and, requiring longer timbers, makes it more expensive.

Sometimes

Sometimes there are piazzas built before the barracks, as those at *Dublin*, if I am rightly informed, which are very convenient; for when the troops are drawn up, and a shower of rain comes, they may shelter themselves under it, to keep their arms dry, and when the companies are to be examined, in regard to their cloathes or arms, it may be done there at any time or season.

In all garrisons it is necessary to build hospitals for the sick and wounded; its bigness ought to be regulated according to the number of troops required to defend it in time of a siege, and it has been found by experience, that out of 25 men, there is generally one sick; yet it ought to be observed, that in fortresses built in low and marshy ground, there are more people sick, than in places standing on a high ground in good air.

Knowing nearly the number of fick people, the number of beds wanted will also be known, and consequently, the bigness of the building, which consists of a long room to hold four rows of beds, and another above it; these rooms the French make 42 feet wide, and therefore if but two rows of beds be required, 20 or 21 feet will do; each bed ought to be 4 feet wide, and 6.5 feet long, and the distance from one bed to the next can be no less than 4 feet, so that as many 8 feet as there are beds, will be the length of the room which is to hold but two rows of beds; or half that length, if it is to hold four rows.

Besides these rooms, there must likewise be lodging rooms for a doctor, surgeon, their mates and attendants, for the nurses and servants; a kitchen and laurdry, as well as a yard to dry their linen: In short, the building is to contain every thing necessary, both for lodging and conveniency of the hospital.

In regard to their fituation, we have spoke of it already, but I must add, that if it is not possible to place it near a river, a canal might be cut to it, because

water

water is absolutely necessary, for cleaning the apparel of the sick and wounded; for neatness in general is absolutely necessary in such places, where the smell of so many fores, wounds, and other sickness, must otherwise

be very offensive.

We have not given any plans of hospitals, because they may be constructed various ways, according to their situations and bigness, which an engineer upon the spot will be acquainted with, and from thence regulate his draughts accordingly, and it would not be amiss to consult the doctor and surgeon about the several conveniencies to be made; this, and his own knowledge in building, will be sufficient to perform such a work in the best manner.

I had forgot that there is often a chapel built at one end of the great room, to perform divine service, and when there are two rooms above one another, the upper one has a gallery looking into it, for the sick to sit

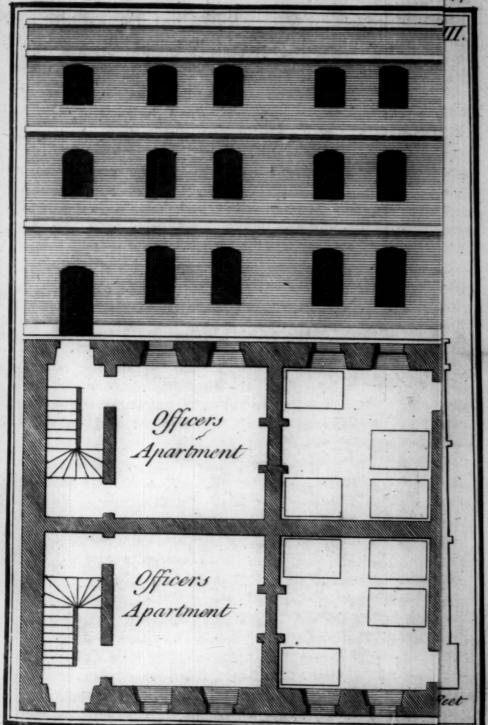
in without being obliged to come down stairs.

The last public buildings we have to treat of, are the store-houses for all kinds of ammunitions, great and small guns, and, if the place is situated near the sea or a navigable river, for cables, anchors, timber, and other

necessaries, to repair and furnish ships.

In a small fortress, such as a citadel or fort, a storehouse of a moderate size will be sufficient to hold the ammunition, and other necessaries for the defence of the place; whereas in a large town lying near the border of a state, it is necessary to have a spacious one for the artillery, in such a manner as to contain every thing wanted in a field train.

A store-house of this fort ought to be built near a river that may carry small crast at least, if possible; in this case a bason ought to be made, to load or unload several boats at a time; such a situation is of great importance, in regard to the saving expences; for it requires a great deal to transport a train of artillery with



Gulo

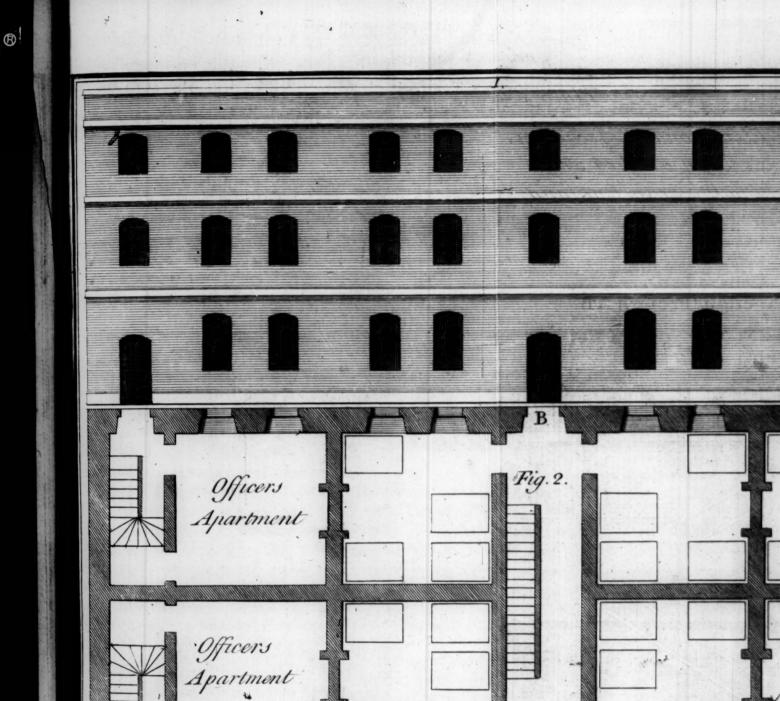
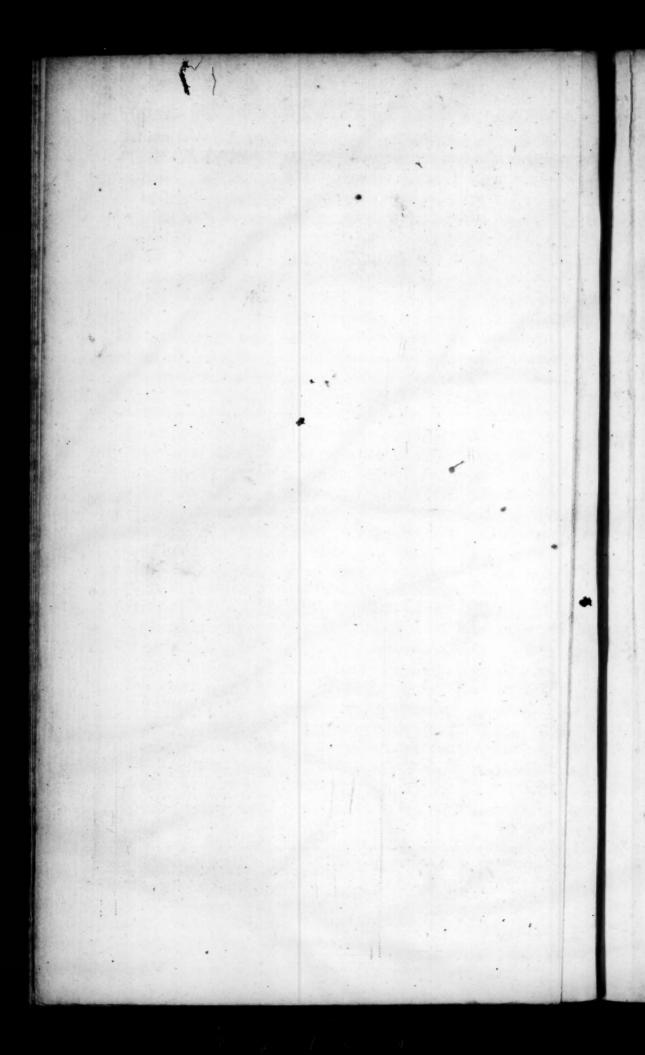


Plate XVIII A Plan Elevation and Section of a Barrack, Such as they are Commonly built here in England Section through AB. Fig. 3.

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all its appurtenances by land to any confiderable distance. And as there is feldom any fortress built but near a great river or the sea, it will always be in the power of the engineer to find a proper place for building the store-house; and what nature wants may be sup-

plied by art.

The ground floor of a store-house ought to consist in a shed to place guns and their carriages, tumbrels, ammunition, waggons, mortars, and their beds; inshort, all the other necessaries which are too heavy to be carried and deposited above: there must likewise be forges for smiths, places for carpenters to work in, to hold iron and wood, and wheelwrights shops, and every

thing of this fort.

The first floor ought to contain an armoury, places to hold all kinds of fmall irons, others for cordage, pontoons, and every thing necessary, that is light and eafily transported. An engineer, who is not perfectly acquainted with every part belonging to the artillery, will not be able to form a right notion of a store-house: there is such a connextion between the business of an engineer and that of an artillery officer, that neither the one nor the other can be mafter of his business, without being tolerably well acquainted with that of the other: I am fensible, that this will be ridiculed by many practitioners, but I leave the unbiassed intelligent reader to judge, whether this notion is right or not: As my intent in writing this work is to instruct young engineers, it is no matter what those say, who think experience is fufficient to shelter their ignorance.

Plate XIX. To give an idea of these kind of works, we have represented the plan of the sourth part of a rectangular shed, in this plate, with the elevation of one of the insides, executed at Woolwich; the width within is 33 feet, the length 282 one way, and 156 the other; the wall is 18 inches thick, having pilasters 15 feet distance from each other, they are two seet broad, and project the wall by 9 inches; the elevation

is 16 feet high at a medium, for the building stands on a small descent: the gate-ways, which are three in each front, and one in the other sides, are 10 feet wide; the arches of the inside walls are 8, as well as the height of the piers from the bottom to the spring.

Plate XX. Here are represented the elevations of the front and outside, together with a section through the middle of the longest side, wherein the section of the roof is represented: As these sigures are drawn on the same scale as those in the former plate, and there is nothing material in them, but what the reader may understand, we shall not enlarge any further on so easy

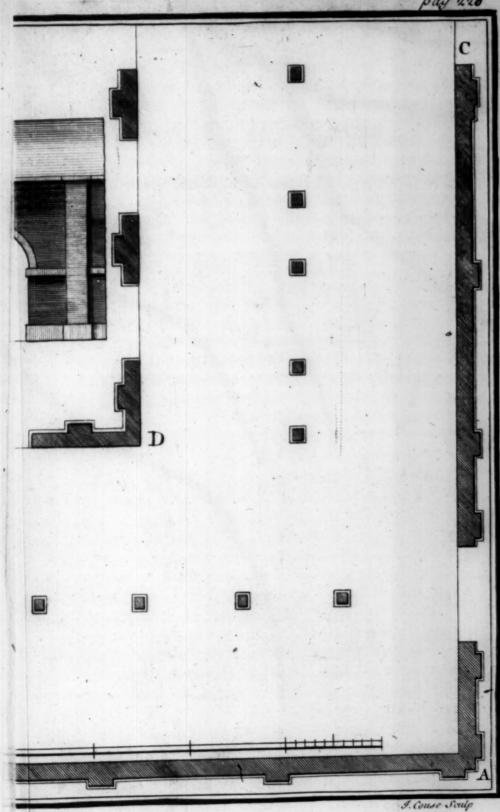
a subject.

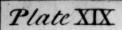
The use of this building is to put under cover the carriages of guns, both for land and sea service, mortar-beds, pontoon-carriages, bread-waggons, ammunition-carts; in short, all kind of carriages, that are used in artillery: and as wood lasts much longer in a place where there passes a free air, than if confined, it was for this reason, that the inside walls have been built with arches, in the manner represented in the preceding sigures.

Besides the great store-houses in large fortresses, several small ones are built in different places, not far from the ramparts, in order to lodge ammunition and other things necessary in a siege, so as to be near at hand; they are supplied from the great ones, when there is any occasion for it: but as their construction does not differ essentially from the former, excepting in their bigness, it would be needless to take any further

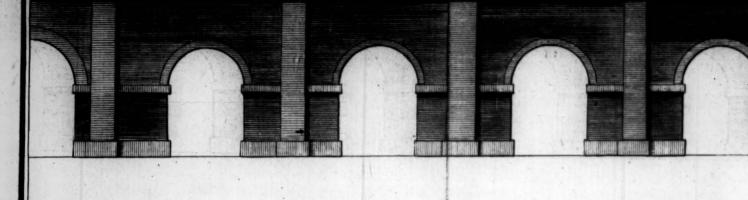
notice of them.

The store-houses built in a maritime town, are not only to have room for artillery and ammunition, but likewise for cables, ropes, masts, anchors, and every thing else, necessary in the sitting or repairing of ships; and this in proportion to the bigness of the harbour or number of ships that generally resort there; these places should have two stories, the lower for heavy things,





Elevation of the Front DE.

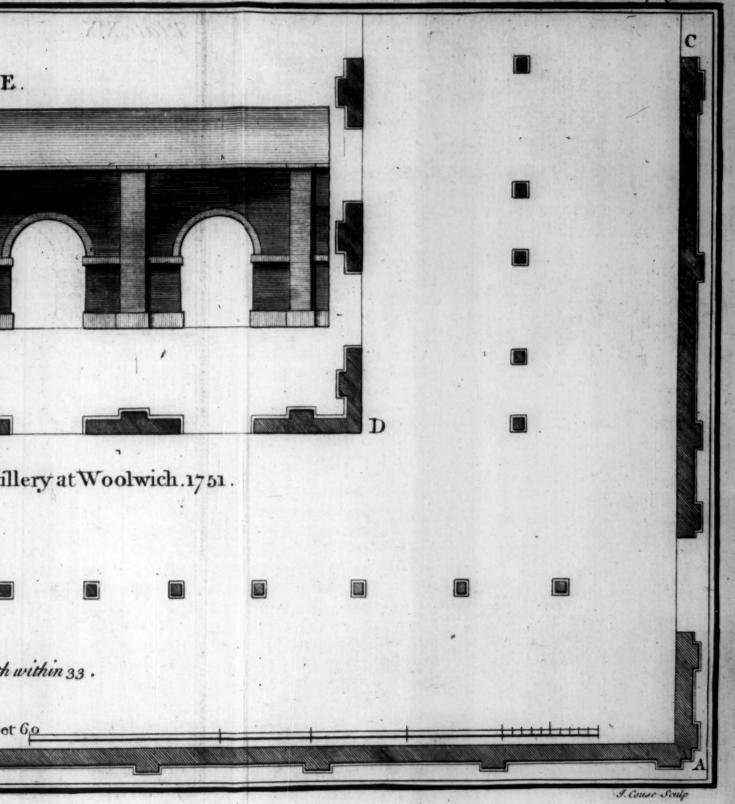


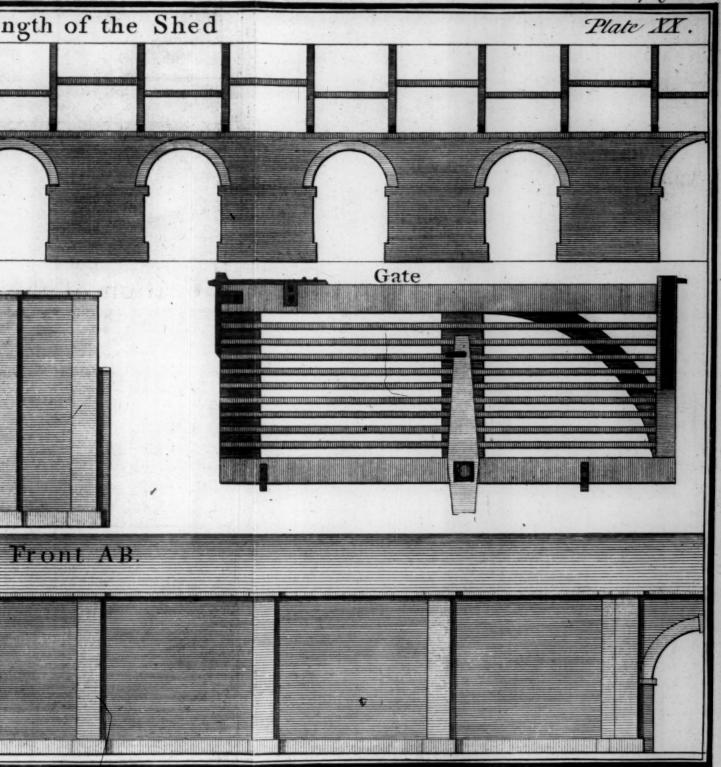
E

A Plan of the fourth part of the Shed for Artillery at

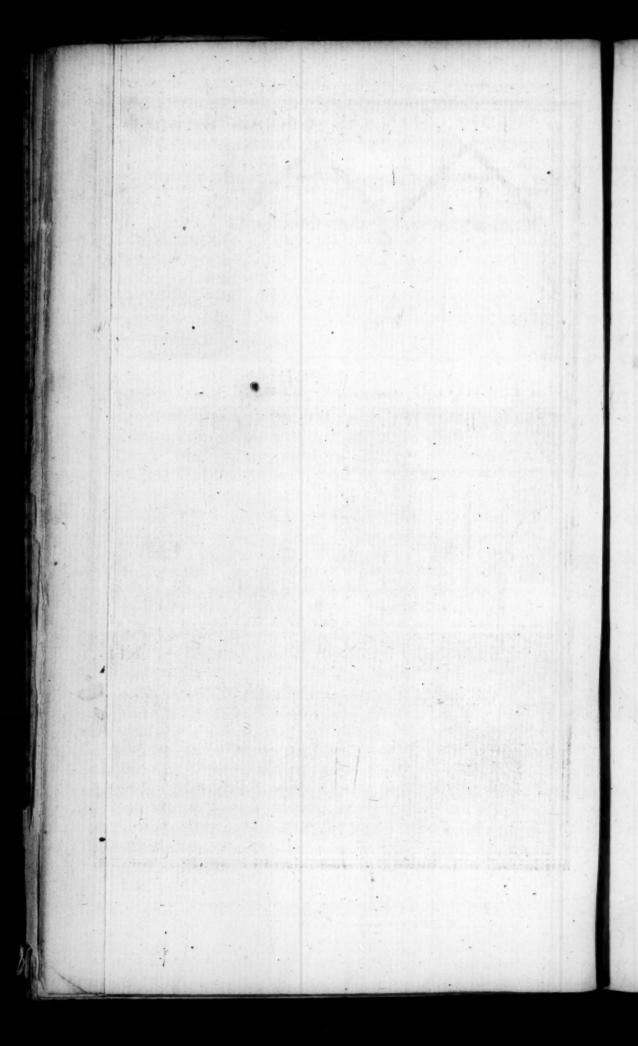
The Long Side is 282 Feet, the other 156, and the weadth within 3.

Foot 60





J. Couse Sculp ..



and the upper for those goods that are light and manageable; their situation ought always to be near the harbour or quay, that the ships may come near them, whereby a great deal of labour may be saved, in the fetching and carrying things from them to the ships.

S E C T. XXI.

Of framing TIMBERS for PARTITIONS, FLOORS and ROOFS.

As an engineer ought not to be ignorant of any thing relating to common architecture, we think it will not altogether be unnecessary, to shew here the different manners of framing timbers on most occasions, this being a branch of his business, especially as the carpenters follow no other rules than those they learn from practice, which are often desective, as will appear hereaster.

Plate XXI. Here are five examples of different partition-frames; the first, second, and fourth, are given by Mr. Smith; the third, and fifth, by Mr. Price; these are the only authors that wrote particularly upon this subject. The first example is in the common way, wherein it has been observed by an artist, that there are more mortifes and tenons than need to be; for if the braces were let into the principal posts, fo as to butt against shoulders of about half an inch deep, and nailed in, they would do the same office in a better manner than being tenoned in, as here represented, and would be done in less than half the time: and as the quarters are only to fustain the laths and plaster, because the weight of the roof is supported by the posts and plates, they have no need of being framed into the upper and under plates, which only take up much time, and will not last longer than when they

are cut and nailed in only, and which is done in a very

little time with little expence.

The example in the fecond figure represents the partition of a warehouse, or of any other large building, where the grinders, or fome other weights are to rest on the king or principal post, E; but it may be observed, that if this wall was to support great weights in two places, it should be inverted, so as the weights may rest upon the posts A, A: for in the first case, the two struts adjoining to the post E, will increase its strength very much, and in the latter, the struts adjoining to the posts A, A, will, by the same reason, increase their strength; but where the weight bears equally on the upper plate, this manner of strutting is needless. The author is also justly blamed for making the joggles in the king-posts A, E, A, as being expensive in the workmanship, and in the waste of timber; it requires likewise much time in the framing of it; and after all, ferves to no other purpose than the first example, which is full as strong, and much cheap-

The example represented by the fourth figure is proposed to raise the height of two stories, the lower of 13 feet, and the upper of 12, or otherwise in one height only, as the fide of an outhouse, hall, or faloon; now it is to be observed, that as joists are supposed to lie on the middle plate in the first case, which is framed into the king-posts EE, and the outward principal posts; the weight at each end must depend on the strength of the tenons, excepting such help as is given to it by the under quarters; the braces are therefore placed exactly the wrong way, because now they support the parts near the middle posts which do not want it, whereas if their ends were turned the contrary way, they would affift the ends, as they should do, as being the weakest part, and the whole would be equally ftrong every where, and they would at the fame time perform perform their office of bracing the frame in a proper manner.

As to the joggles at E, E, in the king-post, they are justly condemned by workmen here as well as in the first example, for the waste of timber, and the loss of time in framing; and it is thought, that if those posts were made a small matter more in breadth, and their struts let into them with a small shoulder, commonly called by workmen, bird's mouth, they would be as

strong and secure as they can be done this way.

The next example in hand, is that represented by the third figure given by Mr. Price, which he supposes to be a partition between two rooms, wherein doors, A, A, are required next to the ends, and therefore has placed a king-post in the middle, and prick-posts between it and the doors; it is here to be observed, that the middle plate, also called intertie, is halved, not only in the prick-posts, but even into the king-post also, which is a great weakening to it, and therefore abfurd; nor indeed is there any occasion for an intertie at all, if the height is intended for one story only; but suppose there was one required, would not its being flighly tenoned into the king post have been a less weakening to it, and have given it a strong bearing, by turning the lower struts the contrary way, to that they are here? It is true, that it is a common practice to halve timbers together, but it should never be done but with very great judgment, and always avoided in braces and struts.

The fifth figure is another example given by Mr. Price, for a partition, wherein three doors are required, one at each end, and one in the middle; the two kingposts and the intertie are again halved into each other; and therefore the same fault may be found here as in the former: the joggles in the king-posts and prickpost are likewise needless; besides, the braces seem to have no other meaning here than to shorten the quarters which cross them, and so are only nailed upon

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them here as well as in all the preceding examples, without tenons or mortifes.

In all Mr. Price's examples of partition-walls, he ties the lower end of the king-posts to the lower plate with an iron band, but for what reason, is not easy to be known, since, as far as I can judge, they seem to be entirely useless, and therefore should never be used.

Many examples of partition-walls are given by authors, of different constructions, and for different uses; but the whole art of framing this fort of work consists in disposing the different parts in such a manner as to make the whole work equally strong; in using no more timber than is necessary, and to join them so as that the work may be done in the shortest time possible, and yet be strong and durable, which cannot be done without a competent knowledge of the rules deduced from mechanical principles, and a good deal of practice, which seldom both meet together; and for that reason, the art of building has received so little improvement in latter times.

S E C T. XXII.

Of FLOORING.

Plate XXII. BEFORE a flooring is begun, there must be made an accurate plan of the building, whereby a judgment may be formed where to place the girders in the most substantial manner; and indeed, this should be done before the brick-work is raised high enough to receive them, that not only the lintels may be well placed over the doors and windows; which ought never be less than 5 by 7 inches; but in those places where the ends of the girders are to rest, if the lintels or bearing pieces are made equal in length to the distance that is contained between girder and girder, they will communicate the weight equally

on the whole wall, and which is much better than when the bearing is on the part just underneath them only, which is the case when the lintels are made shorter; besides, when lintels are so laid, and are 5, 6, or 7 inches in thickness, in proportion to that of the wall, they are a very great strengthening, and tie those parts very firmly together: wherefore they are also called bond timbers; but to prevent mistakes, it must be obferved, that bond timbers are properly those laid in walls where no girders are, as in end and crofs-walls, and which are laid throughout at every 6 or 7 feet in height, and being dovetailed or cogged together at every outward angle of the building, as marked in figure 2, and at every party-wall, as in figure 3, or 4, will most firmly bind the whole together, so that, if even the foundation be bad; they oblige the whole building to fettle together, prevent cracks and fractures, which unavoidably would happen, if they were neglected: It may be observed, that these three different ways of joining timbers are used, but the fingle dovetail, as is marked in the fourth figure, is preferable to the other two, as being more simple, and yet tie the timbers full as well as the others.

The proper places for girders having been determined, it must be observed, to lay them so as the boards lay all one way throughout the middle of the building, so that the whole may be seen one way; for if the joints of the floor of one room are not parallel to those

of another, it would produce a very ill effect.

The fituation of the girders being determined in the plan, we are thereby enabled to find their length, their number, and their distance, which should never exceed 12 feet in any building whatsoever; nor should joists exceed that length: It is also observed in placing of girders, always to lay them the shortest way, and that their ends have at least 14 inches bearing in the wall, excepting those in very small buildings, where the walls

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are of thin dimensions, then their bearing may be reduced to 10 inches.

Nothing being a greater enemy to timber than lime, it is a very good method to lay the ends of girders, lintels, and other bond-timbers in loam; and fir is best preserved by anointing it over with melted pitch and grease, of which the last must be one fifth part, and the other four fifths: If this precaution is neglected, which is commonly the case, the building will never last so long as it would otherwise do.

As the proper scantlings of girders and other timbers have been treated of in the third section, where we have given tables of their dimensions in respect to their length, we shall no farther enlarge upon it here; and having sufficiently explained the situation and manner of laying girders, we shall now proceed to the joists, which are of various kinds, as common-joists, triming-joists, bind-

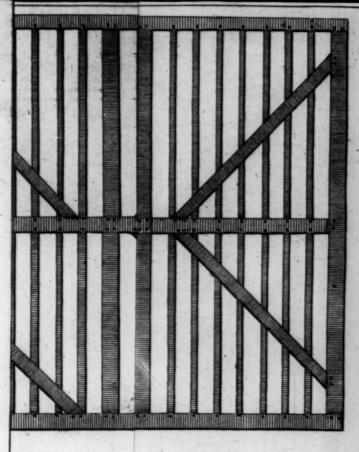
ing-joifts, bridging-joifts, and cieling-joifts.

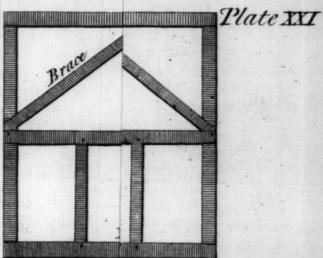
Common joists are those which are framed flush with the upper surface of the girders, and which sometimes are all of equal depth, but less than that of the girders, whereby the girders become lower than the cieling; but the most genteel way is to have every third or fourth joist equal in depth with the girder, whilst the other intermediate joists are of less depth, and between those deep joists, fix small ones to carry the cieling, whereby the under surface of the girders will be concealed, which otherwise have an ill effect.

Triming-joists are such as are framed into two other joists, for other joists to be framed into them, which are against a chimney, or to make the opening for a stair-case, such as are marked by the letter a: as these joists are weakened by receiving many mortises, and having to support the weights of several joists which bear upon them; they are therefore to be made of

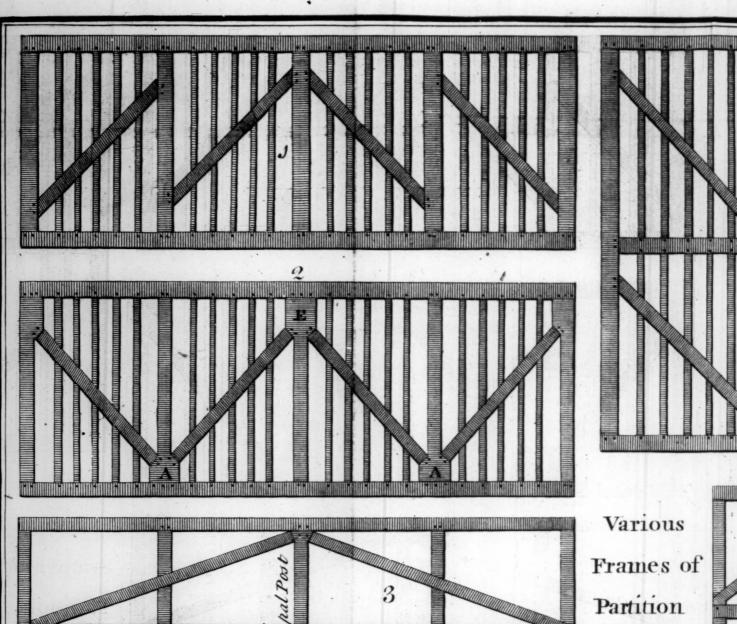
larger scantlings than the common-joists.

Binding joists are those on which bridging joists are laid, and in which the cieling joists are framed; these joists

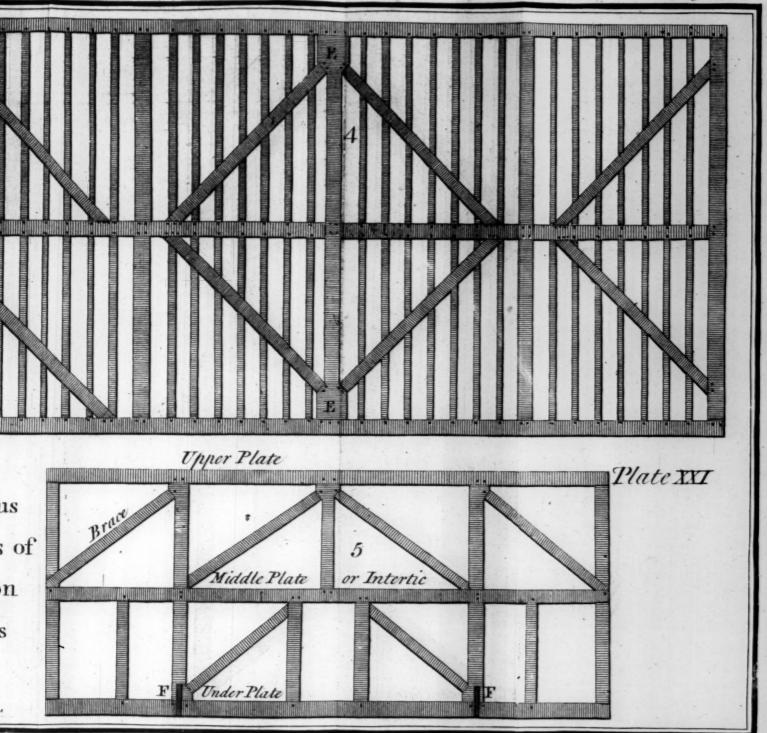




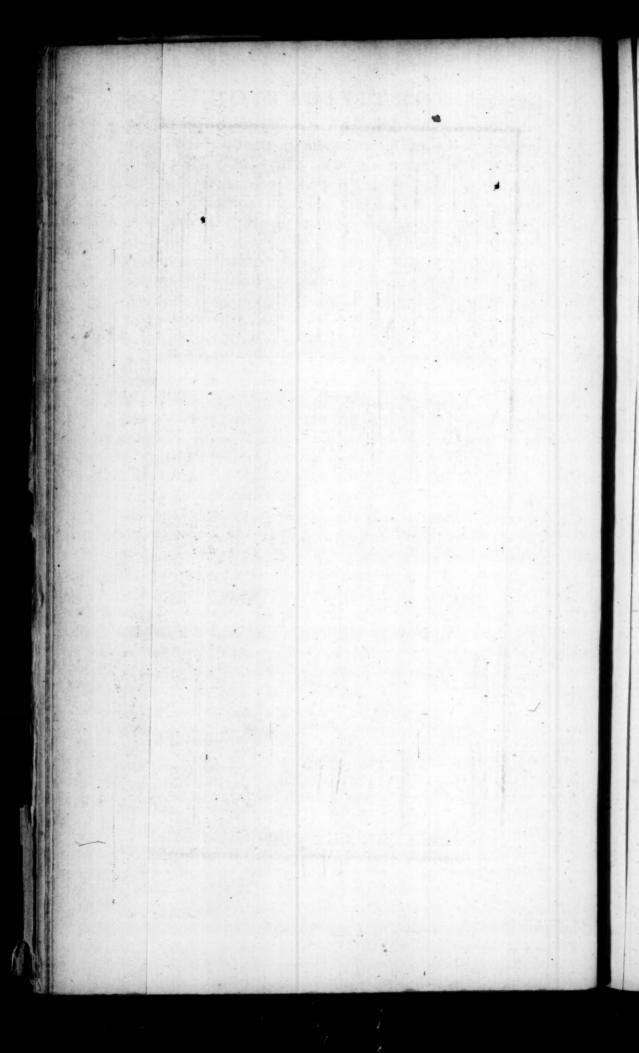
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Partition Walls



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joists are framed shift with the under surface of the girders, and about 3 or 4 inches lower than the upper surface; that the cieling-joists may be shush underneath with them as well as with the girders: their distance is from 3 to 10 feet, and their thickness in proportion to the length of their bearing, as has been shewn in the third section.

The figures 8, 9, and 10, represent the manner in which their tenons and mortises are made by Mr. Price; and which is esteemed by workmen in general much better than any other: but those who are conversant with the principles of mechanics, will easily perceive that neither the one nor the other is good for any

thing.

In order to determine the best manner of making the tenons, it is necessary to consider, that when a great weight bears upon the middle of these joists, or upon any other timber supported at each end by tenons; it is evident, that it will bend a little, and the under part x, as in figure 8, will be the point fix; and therefore when the tenon is placed in the middle as here, the diftance of the line of direction of the force which endeavours to break the joist, from the point fix x, is equal to half the height wv; but on the contrary, if the tenon is placed higher, that diffance becomes greater; and of consequence, the resistance becomes greater, which shews that the nearer the tenon is to the upper part v, the greater the refistance will be: But as the mortise must not be too close to the upper edge, otherwise the tenon would break it; I think the best way is to divide the height x v into four equal parts, one of which is to be the thickness of the tenon, and placed two from the lower end x, and one from the upper v: as to the tenons marked in figures 9, and 10, they ought to be rejected as being contrary to the principles of mechanics. It is to be observed, that all binding-joifts ought to be half as thick again as common joists; because, they being weakened by mortises

and having a greater weight to support, it is necessary

that they should be stronger in proportion.

Bridgings or bridging joists are represented by the letter f, in the first figure, lying on the binding-joists d and which are also represented in figure 6, where n, n, represent the sections of two binding-joists, and d, d, a part of the length of a bridging-joist, and f f, that of a cieling-joist, with the manner of their reception by the binding-joists; the fifth figure is a section which shews the manner of fixing cieling-joists c between the deep joists b, b, where shallow ones, as a, a, are framed in between them, as has been observed to be the most genteel way of framing common joists.

The distance of bridgings is generally about 12 to 14 inches, and their scantlings about 3 by 4 inches, or else 3.5 by 5, and their bearing is never more than the intervals of binding-joists, which is from 3 to 10 feet, as we have observed before, and which are laid even or

flush with the girders to receive the boarding.

Cicling-joifts, the most slender of all other kinds of joifts, as having the least weight to support, are made about 2 by 3, or 3 by 4 inches, according to the strength of the building; these are represented in the first figure by the letter g, whose distances are generally 12 or 14 inches: these joists are tenoned into the binding-joists, as is represented in figure 7, where n represents a single mortise made on the one side of the binding-joists, and r, s, two double ones called pulley-mortises, in the side of a parallel binding-joist to receive the other end of the ceiling-joist. These cicling and bridging-joists are seldom fixed till the building is covered in; when the last are pinned down to the binding-joists. These kind of sloors are called bridging-floors, and are the best fort of carcase flooring.

Having shewn the manner of laying the several timbers for flooring, it remains now to shew how the floors themselves are to be laid; their beauty depends on the colour and smoothness of the boards, without knots, and the closeness of the joints; for which reason, the carpenters plane the boards, and straiten the edges sometime before they are laid, in order that they may

be fufficiently dry, and not shrink afterwards.

As it is not an easy thing to find a sufficient number of boards free from knots, the best are generally picked out for the floors of the principal apartments, and the rest are used in other places less conspicuous. It has been found by experience, that if the boards are ever so dry, and the edges are anew dressed, they will shrink again; for which reason, they never touch them after the first time: and the best way of making close joints is not to nail down the boards, till a twelve-month after they have been laid; this the workmen will not do unless they are obliged to it by agreement, under pretence that it is more work than they can afford to do.

The best wood for flooring in this country is the fine clear yellow deal well seasoned, which when well laid keeps its colour a great while; whereas the white fort becomes black by often washing, and looks very bad. In buildings of consequence the sappy part is cut off, and nothing but the heart is used, but then these floors are very expensive. But in common buildings, which are made by contract, they seldom make even use of dry stuff, unless it is particularly mentioned in the agree-

ment.

The joints of the boards are commonly made plain, fo as to touch each other only; but when the stuff is not quite dry, and the boards shrink, the water runs through them when the floor is washed, and spoils the cieling underneath; for which reason, they often make feather edges in better buildings, so as to cover each other of about half an inch; and sometimes they are made with groves and tenants; this last method, when well executed, appears to me preferable to any other whatsoever.

I am informed, that in the best buildings, the joints are made with dove tails; then the lower edge is nailed down.

down, and the next drove into it, by which the nails are concealed, which certainly makes the floor look much handsomer than when the nails are seen: for when they are washed the nails grows rusty, and appear like so many black spots upon the floor, which has an ill effect.

The manner of measuring floors is by squares of 10 feet each side; so that taking the length and breadth in feet, and multiplying them together; then by striking off the two last sigures as decimals, the remainder will be the content expressed by these squares. Thus a floor of 18 feet by 16, gives 288 square feet, or 2 squares and 88 decimal parts; so that if the price of a square of flooring is known, that of the whole will be easily found by proportion.

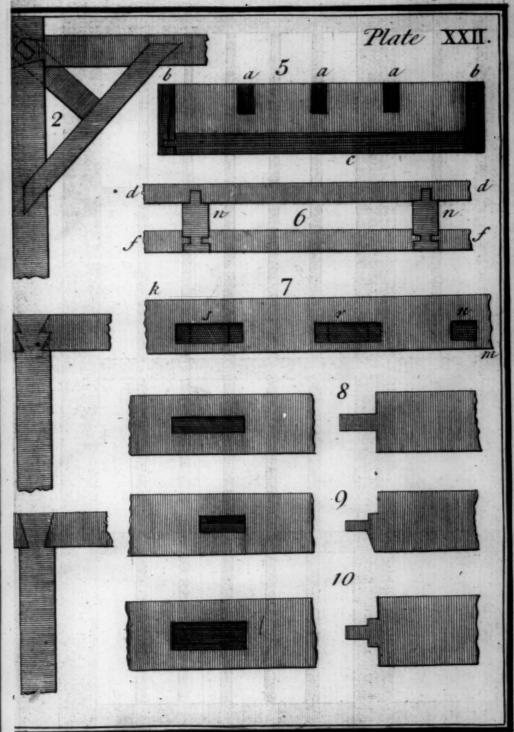
Formerly oaken boards were used for flooring, but at present they are neglected, excepting upon some particular occasions, as in closets and other private rooms: these boards are framed together with pannels, like doors, and polished with wax, which makes them look very beautiful, and are agreeable to those who dislike a wet room; but as they are slippery, and very

expensive, they are much out of fashion.

BECT. XXIII.

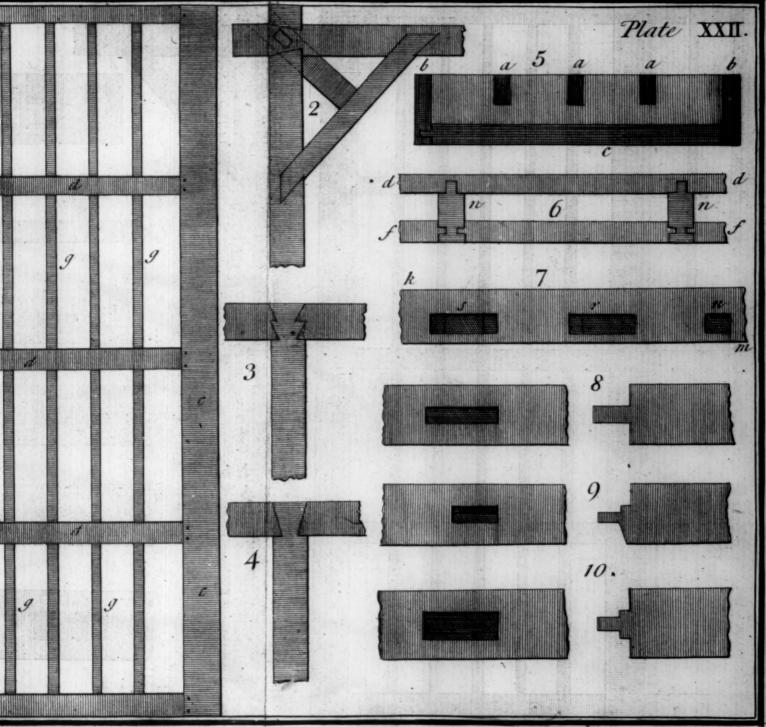
Of ROOFINGS.

Plate XXIII. WE are now come to the formation of roofs, of which the former wall plates are a part, as being the base on which the small rafters stand. We must, after having formed it, according to the plan of the building, and secured its angles, in the manner represented in the second figure, plate XXII. consider the proper distances and



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and places to lay the beams on; where it must be observed, 1. To avoid the joints of the plate: 2. That
their distances be not too great, lest you are obliged
to have large cieling-joists, and large pushins, which
are but a load to a building, and therefore should
not exceed ten feet: 3. That they lay over, or nearly
over, the heads of the principal posts, in timber buildings, and on the middle of the piers, when they are
of brick or stone.

The fituation and length of the tie-beams being determined, their under furface at each end being equal to the breadth of the wall-plate, is dovetailed an inch and a half or two in depth, according to their strength, and which are let into both these plates, in the manner represented by the third and fourth figures, plate XXII; but, as it has been shewn already, with a single dovetail; as in figure 4. If the breadth be divided into three equal parts, make the narrow part of the dovetail one, which to the end opens to the whole breadth of the beam. When the tie-beams are thus dove-tailed into the plates, they are then said by the workmen to be cogged down, and ready to receive the cieling-joists and principal rafters.

But before the principal rafters can be framed, the height of the pitch, and their length must be determined; the pitch of every roof ought to be made according to its covering; which is of lead, pantiles, plaintiles, or slates; these are all the different coverings used in *England*. The usual pitches are the pediment-pitch, common pitch, generally called true pitch, and

the gothic pitch.

Pediment pitch is that whose perpendicular height is equal to two ninths of the breadth of the building; because the height of a pediment is likewise two ninths of its base; this pitch is used when the covering is lead. Common pitch is that whose rafters are the three fourths in length of the breadth of the building; when it spans the building all at once; but is oftner divided

into two equal pitches; and it is used when the covering

is of plaintiles.

Gothic pitch, is that when the length of the principal rafters is equal to the breadth of the building, and therefore is equilateral; this pitch is used when the covering is of pantiles; some workmen would have the breadth of the building divided into seven equal parts, the perpendicular height to have two of them, and the length of the rafters to be four; and that this pitch may serve for coverings of lead or pantiles: on the contrary, others will have the perpendicular height to be one fourth of the breadth, when the covering is lead, which is something less than what has been assigned above for that covering.

That the perpendicular height should be the three eighths of the breadth in pantiles covering, which is widely different from the former; or that the perpendicular height may be found by describing an arc from the extremity with a radius of two thirds of the breadth of the building. Lastly, the perpendicular height to be equal to half the breadth for plain-tiles covering, which makes the rafters somewhat shorter than in the pitch given before for that covering; and the length of the rafters to be five seventh parts of the breadth of the building for slate coverings, which is therefore nearly the same pitch as that for plain-tiles

These are the various pitches commonly used for the different coverings, and seem to depend chiefly on the builder's fancy. We have proved in our *Elements* (art. 566.) of Mathematics, that if the height is 6 seventeenth parts of the breadth, or, which is nearly the same, if the height is one third of the breadth, the roof will be stronger than any other of the same scantlings; and therefore, if the scantlings are strong in proportion to the weight of the coverings, this pitch may serve upon

all occasions.

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Although the principal rafters are commonly made equally strong every where, yet some think that if they were at their seet nearly as thick as the breadth of the tie-beams, and to grow less towards the upper end, by one sixth part, they would be better; which is certainly true, because their centers of gravity become nearer to the point of support; they require less timber; and as the rafters may as well be sawed in this manner as in the usual way, I see no reason why this method should not be used.

The king-posts should be as thick as the tops of the principal rafters, otherwise they will not be able to receive them; and their breadth of sufficient strength to receive the struts that are designed to be framed into them. Some will have it that the struts should diminish upwards as well as the rafters; but this would be carrying niceties surther than is necessary; when the lower ends of the rafters are strongest, the purlins, collar-beams, and struts, should be placed something higher than the middle of the rafters, that the bearings may be proportional to the strength, and not in equal parts, as is usual.

Purlins must have the same thickness as that part of the principal rasters to which they are framed, and their breadth is generally made to their thickness, as 4 to 3; therefore the breadth being 8, the thickness must be 6: tho' this is the rule carpenters go by, yet their dimensions ought to be determined by the rules given in the third section, part I.

Purlins are generally framed into the principal rafters; but, in my opinion, they should rather be laid in the collar-beams, because the rafters are not so much weakened by mortises, and the strength of the purlins will then not depend on the tenons: when they are framed into the principal rafters, their length cannot be more than the distance between two contiguous rafters, which is from ro to 12 feet only; but when

they

they are laid in the collar-beams, they may then be twice or thrice that length, according as the flrength of the stuff will allow.

Small rafters may be in their fcantlings 4 inches by 2.5, or 4.5 by 3.5, or else 5 by 3.5, according to the nature and strength of the principals, and their length in a purlined roof should not exceed seven feet: it is best to frame two rows of purlins, when the principal rafters are very long, in the manner represented in the first figure, plate XXIII. by the letters A, A; which figure represents the roof, as a plain surface; but the method of framing the purlins in a right line, as here represented, is not to be recommended; because when the mortises in the principal rafters are against one another, they are not only weakened very greatly in those parts, but you lose the pinning also, and therefore they should be framed, as represented by the letter B in the fame figure.

The use of this figure is, to determine the number and fituation of the principal small and jack rafters; the principal rafters are those marked by the letter D, and lie through the body of the plan, with tenons reprefented in the middle; the small rafters are those marked f, between the principals and the jack-rafters those short ones, whose tops bear against the hip-rafters C, and are marked by the letter E; the purlins are marked by the letters A and B; as to the other parts of a roof, which cannot be feen in this figure, they are re-

presented in the following section.

This figure represents the section of a large roof, having a king-post and two struts to support the principal rafters, the tie-beam is supposed to rest in the middle upon some party or partition-wall, otherwise that beam would not be able to support the roof; because the greatest weight, which is under the king-post, would rest upon the weakest part, as has been shewn in the third fection, part I.

Fig. 3. This figure is the section of a roof to be covered with pantiles; the length of the rafters is the two thirds of the breadth of the building, and the height one half; there is a lodging-room made in the middle; this roof is very ftrong, and may ferve almost in any building, especially if the tie-beam is supported in the middle by a party-wall.

Fig. 4. This figure represents a roof, whose perpendicular height is three eighths, and the length of the rafters five eighths of the breadth; this roof is also very ftrong, but I think that in small buildings the king-post with its two struts might be left out without any inconveniency; because the two prick-posts together with their struts are sufficient to support the raf-

Fig. 5. This figure is a fection of a roof of pediment-pitch, with a valley in the middle to take off the barn roof aspect, which it otherwise would have, if the rafters were continued up to an angle; in this roof are made two lodging-rooms, as being framed with a collar-beam and middle-post, which last must be supported by a party-wall, otherwife the tie-beam will fcarcely be able to support the weight upon it, with-

out its being of very large dimensions.

It may be observed, that the posts in fig. 2, 3 and 4, have all joggles, which are by many workmen not approved of, on account of the waste of timber, and the length of time to frame them; in order to fatisfy those that are for plain-work, and yet make it strong and durable, it will be fufficient to cut the tenons of the flruts which enter into these joggles, as well as the mortises, in the same manner as they are represented here by the joggles, which will do very near as well; for all tenons cut at right angles will bear the pressure of the posts in the strongest manner that can be. It must likewise be observed, that all the iron bands represented in these roofs, are thought by the workmen to be very useful in strengthening the work, though needless in

my opinion.

As workmen differ very much in their manner of framing roofs; it is impossible to give such rules as will satisfy every body; but what has here been said, together with the principles given in the third section, part I. of the strength of different scantlings, will be sufficient to the intelligent reader, to frame all sorts of plain roofs, upon any occasion, in the best manner, which is all we propose in this work: As to those called mansard, or broken roofs, and those for domes or cupolas, which are the most difficult of all carpenters work, their construction rather belongs to a compleat architect than to an engineer.

But before we conclude this section, it will not be unnecessary to shew how the length and position of the hip rafters C, C, sigure 1, are to be found; the distance P Q of the last principal rafter D from the end P of the roof is always equal to half the breadth P S of the building; and having the length Q R of the principal rafter D, that of the hip-rafter P R is likewise given, as being the hypothenuse of a right angled tri-

angle PQR.

And because the perpendicular height of the roof is given as well as the diagonal drawn from the point P to the foot of the perpendicular dropt from the point R to the plan of the building; the inclination of the hipraster C, may be found by a ruler and compasses; or, by trigonometry, thus; The length of the hipraster PR is to the perpendicular height of the roof, as the radius is to the tangent of the angle made by this raster and the plan of the building.

Of CEILING.

Although the manner of ceiling is very common, yet it is necessary, that the young engineer should know how it is performed: In buildings of no great consequence,

consequence, the laths are nailed on the joists, so as a part of the girder appears below the ceiling; this is done in view to get 5 or 6 inches in the height of the room; and the part of girders that appear are covered with deal boards, with a little cornice round it; and painted with the same colour as the wainscot. The plaister for ceiling is made of lime and hair, to make it stick the better, and laid on very smooth; when it is dry and has any cracks in it, as commonly happens, it is passed over with a trowel dipt in thin plaister, this is continued till it is quite smooth, and without any cracks; after this it is white-washed two or three times over, with lime-water and size, till it appears of a fine white.

But in buildings of any consequence, ceiling-joists are framed into the girders, so as to be even with the under surface, as has been observed before: As these joists are put in after the frame of the floor is made, and just before the ceiling is finished; one of the mortises is made about a foot long, sloping so as that when the tenant at one end is fixt into the mortise, the other may slide through the other till it becomes perpendicular to the girder where it is pinned down.

As to ceilings made with various work, or that are painted, the curious reader may confult books of architecture, which treat of them; we shall only add that ceilings are measured by the yard of 9 feet square.

of WAINSCOTING.

Formerly wainscoting was made with oak, and it is from thence it has derived its name, but at present white deal is used only; the rooms were commonly wainscoted quite up to the cieling, and terminated by a cornice; but the later custom is to carry it only up chair high, that is from two to three seet; the rest of the wall is covered with slowered paper, which is very cheap and beautiful, or else it is finished with slucco

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covered with hangings; to prevent the paper from being spoiled by the dampness of the wall, it is pasted

on thin cloth, and fixed in frames.

Walls should never be wainscoted before a twelvemonth standing at least, two or three years would be better; otherwise the pannels will unglue, do what you will, and shrink in dry weather, whereby it will be so spoiled that all the repairs that can be made will never look well, so that all the trouble and expences will en-

tirely be loft.

Though the wall is dry, if the stuff is not so, it will produce still the same effect; and as dry and well-sea-soned stuff is much dearer than that which is green, and not many workmen have it in their power to keep always a stock of dry stuff before-hand; it is a very difficult matter to have this work performed as it ought to be: I have seen a house that was repaired three times in five years, and now is good for nothing; because the walls were not dry, and the stuff not sufficiently seasoned; and if government work, which is always well paid for, is so badly executed, what must a private person expect, if he is not very careful in his bargain, and does not understand the work himself.

Wainscoting is measured by the square yard of 9 feet, and all the turnings of the mouldings are measured by a thread, and looked upon as plain, excepting the cornice, which is measured and paid by the foot in length.

Of HOUSE-PAINTING.

As the various colours for priming and painting are now-a-days made up ready for use, and sold in shops, I shall say nothing about them; but only observe that all painting in and about the house should be well primed, and passed over twice with the same colour the rooms are to be of, and great care must be taken to see that the colour is laid sull, even, and smooth, according to the grain of the wood; for when the brush is drawn cress

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cross the grain it never looks well; this is to be understood to be done from the beginning to the entire sinishing of it; or else it will be to no purpose.

In all out-door painting, the colour's should be mixed up with linseed oil, Spanish white, Spanish brown, and red lead in the priming, and finished with white lead; this done, it will resist the weather, and last a great while.

Painting is measured by the square yard, in the same manner as wainscoting, that is, all the mouldings are measured with a thread; the sashes of windows are paid by the piece; if the doors and their frames are painted in mahogony colour, the price is somewhat more than that of common painting; this some workmen perform so well, as to appear at a distance as well as that wood itself. When chimnies are lined with Portland stone, they are often painted like marble, and when it is well done, look very neat for three or four years.

Of TYLING-ROOFS.

There are various forts, such as plain-tiles, pan-tiles, ridge, hip, gutter, paving, and Dutch-tiles: plain-tiles are the common fort which are used in covering of houses; they are about 10.5 inches long, six and a quarter broad, and half an inch and half a quarter thick; but in the country they vary something from these dimensions; they weigh about 2.5 pounds, that is 100 weigh nearly 2500 pounds. Tyling is measured by a square of 100 square seet, and the number of tiles required for such a square depends on the distance of the laths; which when 6 inches, requires 800; when 6.5 inches, 740; when 7 inches, 690; when 7.5 inches, 640, and when it is 8 inches, but 600 tiles.

Pan-tiles are of a quadrangular figure, when flat of about 13 inches long, 6 or 7 inches broad; they are R 3

bent cross-ways in the form of an S, only one of the arches is about three times as big as the other; so that when they are laid on a roof, one of the edges which is least bent is covered by the edge of the other that is most bent, so that the roof looks like furrows, one high and the other low; these tiles serve mostly for low roofs, such as stables, sheds, and outhouses; about 600 will cover 100 feet square.

Ridge-tiles are used to cover the ridges of houses, and are made in the form of a semi-cylindric surface, of about 13 inches in length, and of the same thickness as plain tiles; their breadth at the outside measures

about 16 inches or less.

Hip, or corner tiles, are at first made flat like plaintiles of a quadrangular figure, whose two sides are right lines, and the ends arcs of circles; the upper end concave, and the lower convex, the latter being about seven times as broad as the other; they are about 10.5 long, but before they are burnt are bent upon a mould in the form of a ridge-tile, and have a hole at the narrow end to nail them on the hip-corner of the roof.

Gutter-tiles are made like corner-tiles, only the edges at the larger ends are turned up for about four inches: these tiles are seldom used where lead is to be

had, as being better for this purpose.

Dutch-tiles are commonly used in chimnies; they are made of a whitish earth, glazed and painted with various figures, such as birds, slowers, or landskips, in blue or purple colour; and are about 6.5 inches. each way, and three quarters of an inch thick: when these tiles are properly set with good mortar, they look very beautiful, and cast a greater heat than stone; for being very smooth, and glazed, the rays of heat striking upon them are all resected backward into the room, especially when the sides of the chimnies are oblique or in the form of circular arcs.

Pan-tiles are laid in mortar, because the roof being very flat, and many tiles being warpt in the burning,

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they will not cover the roof so well as that no water can pass between them. Sometimes these tiles are varnished with a dark brown colour; which makes them last a great while, and look better than the others, but are dearer in proportion.

Plain-tiles are not laid in mortar, but pointed only in the infide; as to the ridge and corner-tiles they are all laid in mortar, because they lie seldom so close, as not to admit any water to pass between them. There are also used tiles in paving, that are either square or hexagonal, which when well burnt and laid in good mortar, look very neat, and last long; but as paving in general is so well known, it would be needless to say any more about it.



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PART

PART IV.

Of AQUATIC BUILDINGS.

S these kind of works contain a greater variety than those constructed on dry land, and re-A quire much more skill and knowledge both of the theory and practice; no leffer work than Mr. Belidor's Architecture Hydraulic, is necessary to give a true knowledge of their construction and execution, according to the different fituations and circumstances; As this author had the affiftance of the greatest engineers in France, who have more experience, and knowledge both in theory and practice, than any others in Europe; so no man had a better opportunity to give every thing necessary relating to this subject. Since therefore his works are, or ought to be, in the hands of every engineer, we shall content ourselves, to give here some general principles, together with particular observations of the most material parts of these buildings, for the fake of those, who have no opportunity to perule fo extensive a work as his.

SECT. I.

Of STONE-BRIDGES.

THE fituations of bridges are easily known, and need no explanation; the only thing to be obferved is, to make them cross the stream at right angles, for the sake of the boats that pass through the arches, with the current of the river; and to prevent the continual striking of the stream against the piers, which

which may endanger them in a long course to be

damaged and destroyed in the end.

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Bridges built for a communication of high roads, ought to be fo strong and substantial as to be proof against all accidents that may happen, to have a free entrance for carriages, afford an eafy paffage to the waters, and be properly adapted for navigation, if the river admits of it; therefore the bridge ought to be at least as long as the river is wide in the time of its greatest flood; because the sloping of the water above may cause too great a fall, which would prove dangerous to the vessels, and occasion the under graveling the foundation of the piers, and abuttments.

To this may be added, by reducing the passage of the water too much, in time of a great flood, it might break through the banks of the river, and overflow the adjacent country, which would cause very great damages; or, if this fhould not happen, the water might rife above the arches, and endanger the bridge

to be overfet, as it has happened in many places.

When the length of the bridge is equal to the breadth of the river, which is commonly the case, the current is lessened by the space taken up by the piers, for which reason, this thickness should be no more than is necessary to support the arches; and it depends, as well as that of the abuttments, on the width of the arches,

their thickness, and the height of the piers.

The form of the arch is commonly semi-circular; but when they are of any great width they are made elliptical, because they would otherwise become too high; as has been done at the Pont Royal, at Paris, where the middle arch is 75 feet, and its height would have been 37.5 feet, instead of which, it is only 24 by being made elliptical.

Another advantage of much more importance arises from the oval figure, which is, the quantity of mafonry of the arches is reduced in the fame proportion as the radius of the arch is to its height. That is, if

the radius is 36 feet, and the height of the arch 24, that is, three fourths of the radius, the quantity of masonry of the arches is likewise reduced to three fourths; which must lessen the expence of the bridge

confiderably.

When the height of the piers is about fix feet, and the arches are circular, experience has shewn, says Mr. Belidor, it is fufficient to make the thickness of the piers the fixth part of the width of the arch, and two feet more; that is, the thickness of the piers of an arch of 36 feet ought to be 8 feet; those of an arch of 48 feet to be 10.

When the arches become of a great width, the thickness of the piers may be reduced to the fixth part of that width; but the depression of the two feet is not done at once; that is, in an arch of above 48 feet, 3 inches are taken off for every fix feet of increase of the width of the arch. For instance, the thickness of the piers supporting an arch of 72 feet wide, should be 14 feet, according to the preceding rule; but by taking off 3 inches for every 6 feet, above an arch of 48 feet wide, the thickness of the piers is reduced to 13 teet: Consequently, by following the same rule, the thickness of the piers supporting an ach of 16 fathoms wide, will be 16 feet; all the others above that width are the fixth part of the width.

After this Mr. Belidor gives a rule for finding the thickness of the piers which support elliptic arches, and makes them stronger than the former: The abuttments he makes one fixth part more than the piers of

the largest arch.

It is plain, that these rules are merely guess-work, determined from some works that have been executed. But tho' examples are necessary to confirm the truth of the theory, yet they are not sufficient to form, from one or two bridges that have been built, a general rule for others of different forms or dimensions, without either making some stronger or weaker than they ought

to be; besides, granting this rule to be true, yet when the piers are of any other height, we are quite lest in the dark; and therefore, it is necessary to have recourse to theory, in order to find how much the piers are to vary in their thickness, according to their height, and the width of the arches: But, previous to this theory, it is necessary to know, the proper thickness of the arches at their key-stones, because that of the

piers depends partly on it.

The thickness of the arch-stones, I must confess, is not to be determined by theory, at least that I know of; nor do those authors who have written on the subject agree amongst themselves; Mr. Gautier, an experienced engineer, in his works, makes the length of the arch stones, of an arch 24 feet wide, two feet; of an arch 45, 60, 75, 90 wide, to be 3, 4, 5, 6 feet long respectively, when they are hard and durable; and something longer when they are of a soft nature; on the contrary, Mr. Belider says they ought to be always one twenty fourth part of the width of the arch, whether the stone be hard or soft; because, if they are soft, they weigh not so much.

But that the length of the arch-stones should be but a foot in an arch of 24 feet wide, 2, 3, 4, in arches of 48, 72, 96, feet, it appears to me impossible; because the great weight of the arches would, as I imagine, crush them to pieces, by the pressure against one another; and therefore Mr. Gautier's rule seems to be much preferable: As he made the length of the archstones to increase in a slower proportion, from 10 to 45 feet wide, than in those above that width; we imagine, that the latter will be sufficient for all widths, whether they are great or little: Therefore in the following computation, we shall suppose the length of the archstones of 30 feet in width to be two feet, and to increase one foot in sisteen, that is, 3 feet in an arch of 45 feet, 4, 5, 6, in an arch of 60, 75, and 90 feet;

and so the rest in the same proportion; this being premised, we shall proceed to shew how the thickness of the piers is to be found.

PROBLEM.

Plate XXIV. Fig. 4. To find the thickness BC of the piers, when the arch is terminated by two concentric semi-circles, and there is a wall RN above the middle of the piers whose height is equal to that of the arch, and its base to the difference between the breadth AD of the pier, and twice the thickness AG of the arch.

Let the radius O M pass through the center of gravity L of half the arch GE, LK, and LI, perpendicular to O A and O L; then if the radius O A of the interior circle be called a, the radius O G of the exterior one b; their difference AG, d; O K or KL=m, the area GE of half the arch; the height AB of the piers c, their thickness BC=z; lastly, let unity be to r, as the radius is to the semi-circumference; or, which is the same, let r = 3.142 nearly; then by what has been said in the second problem, section II. of the first

part; we have 4n = rbb - raa, $\frac{3r}{4}m = a + \frac{bb}{a+b}$, g = c + 2m - a, and 2ng - 2nz for double the momentum of the arch's preffure against the pier.

Now because the base R G of the wall above the pier is equal to A D — 2 A G, or z = 2d, and its height R N = b, bz = 2bd will express the area of that wall, and as the line which passes through its center of gravity perpendicular to B C bisects that line; $\frac{1}{2}z$ will be its distance from the point fix C; we have $\frac{1}{2}bzz = bdz$ for its momentum; and as the momentum of the pier C A, has been found in the above-cited problem to be $\frac{1}{2}czz$; double the sum of these

two last momentums being made equal to 2 ng - 2 nz. gives bzz - czz - 2bdz = 2ng - 2nz; or if we suppose b+c=s, and n-bd=sq; this equation becomes szz + 2sqz = 2ng; whose square

root is $z+q=\sqrt{\frac{2}{5}}ng+qq$.

REMARK.

We have shewn in the second section of the first part, after problem the fecond, that on account of the cement and roughness of the stones, the weight of the arch, or, which is the same, the area n of GE, should be diminished by one third or more, in order to have the true momentum of the arch; and as in bridges, the parts between the arches are filled up with loofe stones, their weight will be greater in this case, than it would be otherwise; The question is therefore to find what value ought to be affigued for n, in order to find the thickness of the piers able to support the pressure of the arch, when it is loaded with this additional weight. For fince the spaces above the arches are always fimilar when the upper part of the bridge is horizontal, and consequently proportional to the fimilar parts A G F E, and this is nearly fo in bridges; it is manifest, that if the whole area AGFE, is taken for the value of n, and the piers are sufficiently strong in one case, it will be so in all others.

As the value of n cannot be estimated so truly as from some bridge that has been executed, and is look. ed upon by the masters of this art as a model to go by; fo we shall make it appear, that if n expresses the whole area AGFE; the thickness of the piers will come out nearly the same as those of the Pont Royal

at Paris, which support the greatest arch.

According to Mr. Belidor, in an arch of 75 feet wide, the thickness of the piers whose height is about 6 feet, should be 13.5, when the arch is circular; and 15 feet

when it is elliptical, as that of the above-mentioned bridges; But we have shewn in the second section, that the pressure of an elliptic arch is no greater than that of a circular form, on account of the weight being less in the former than in the latter; and fince, according to the problem above, the thickness of the piers of such an arch is found to be 14 feet, when they are 6 feet high, as in those of the Pont Royal; it is evident, that the value of n affumed here, agrees with the above rule as nearly as can be expected.

Now as Mr. Belidor fays, that his rules are agreeable to the practice of the greatest masters in that branch of engineering, we may prefume, that the thicknesses of the piers, we have found, will be fufficient in all the different cases that can happen, with this precaution however, that the piers are made of strong folid stones,

laid in the best and most substantial manner.

It is to be observed, that the thickness of the piers here found, are such as if there were but one single arch; but when there are arches on each fide, the preffure of the one destroys that of the other; but as all the arches cannot be built together, it is of absolute necessity, that the piers should be able to resist the pressure of each arch, independent of the adjacent ones; for which reason, it is necessary to build the wall GN above the pier before the arches are formed, as Mr. Labely has most judiciously done at Westminsterbridge; for by this means, the arch will be in no danger to fall and cause needless expences. As to the parts between the arches, and the wall G N, they ought not to be filled up till fuch time as the arches on each fide are finished.

TABLE containing the thickness of the piers of BRIDGES.

	6	9	12	15	18	21	24
20	4.574	4.918	5.165	5.35°	5.492	5.610	5.698
25	5.490	5.913	6.216	6.455	6.645	6.801	7.930
30	6.386	6.816	7.225	7.513	7.746	7.939	8.102
35	7.258	7.786	8.200	8.532	8.807	9.037	9.233
40	8.404	8.691	9.148	9.523	9.835	10.101	10.328
45	8.965	9.579	10.077	10.489	10.837	11.136	11.394
50	9.805	10.454	10.987	11.435	11.817	12.146	12.434
,55	10.640	11.245	11.882	12.364	13.019	13.149	13.218
160	11.400	12.110	12.718	13/281	13.723	14.109	14.314
65	12.265	13.025	13.648	14.185	14.654	15.082	15.433
70	13.114	13.869	14.517	14.049	15.573	16.011	16.400
75	14.000	14.705	15.336	15.965	16.480	16.940	17.354
80	14.747	15.542	16.234	16.842	17.381	17.864	18.298
85	15.513	16.328	17.041	17.674	18.237	18.742	19.198
90	16.373	17.201	17.929	18.578	19.157	19.679	20.152
95	17.184	17.826	18.772	19.438	20.036	20.577	21.068
100	17.991	18.848	19.610	20.293	20.908	21.466	21.976

The first horizontal line expresses the height of the piers in seet, from 6 to 24 seet, each increasing by 3: the first vertical column, the width of arches from 20 to 100 seet for every 5 seet.

The other columns express the thickness of piers in feet and decimals, according to the respective height at the head of the column, and the width of the arch

against it in the first column.

Thus for example, let the width of the arch be 60 feet, and the height of the piers 12; then the number 12.718, under 12, and against 60, expresses the thickness of the piers, that is 12 feet, and 8.6 inches; we must observe again, that the length of the key-stone

is 2 feet in an arch of 30 feet wide; 3, 4, 5, 6, in an arch of 45, 60, 75, 90; that of 20 feet width one foot 4 inches; and the length of any other width is found

by adding 4 inches for every 5 feet in width.

As this table contains the thicknesses of piers in respect to arches that are commonly used in practice, we imagined, that to carry it farther would be needless; besides, if any other arch of a greater width was proposed, the strength of its piers may be found by the foregoing problem, as well as that of any intermediate one not inserted here; or because the difference between the thickness of the piers of any two contiguous arches is but small; those between any two marked here, may be made equal to half the sum of the next below and above it: thus the thickness of the piers of an arch 52 or 53 feet wide is nearly equal to 10.222, half the sum of the thicknesses 9.805 and 10.64 of the arches 50 and 55 feet wide, when the height of the piers is 6 feet.

Rectangular piers are seldom used but in bridges over small rivers; in all others, they project the bridge by a triangular prism, which presents an edge to the stream, in order to divide the water more easily, and to prevent the ice from sheltering there, as well as vessels from running soul against them; that edge is terminated by the adjacent surfaces at right angles to each other at Westminster bridge, and make an acute angle at the Pont Royal, of about 60 degrees; but lat terly the French terminate this angle by two cylindric surfaces, whose bases are arcs of 60 degrees, in all their new bridges.

When the banks of the rivers are pretty high, the bridge is made quite level above, and all the arches of an equal width; but where they are low, or for the sake of navigation a large arch is made in the middle of the stream, then the bridge is made higher in the middle than at the ends; in this case, the slope must be made easy and gradual on both sides, so as to form above

one continued curve line, otherwise it appears disagreeable to the eye. Mr. Belidor will have the descent of that flope to be one twenty fourth part of the length; and Mr. Labely fays he made it one twentieth part only, which he thinks to be fcarce preceptible; but as Westminster bridge is 1220 feet according to his own account; if half this breadth be divided by 20, we shall find 30.5 for the difference between the height of the middle arch and the end of the abutments: now if this can be called scarcely perceptible, I should be glad to know how far this descent may be carried, fince it is plain, that the flope of Westminster bridge is too much by a good deal, according to the best judges; for the beauty of any bridge confifts, in that one may fee from one end to the other, like a street, if it is posfible; or, if the nature of the fituation does not permit it, the least rising is the best; for which reason, I should think that one fiftieth part of the length is quite fufficient for the descent; whence, according to this rule, the middle arch of the above mentioned bridge would be about 11 feet higher than the ends of the abutment, which, in my opinion, would have looked very well.

It may be said, that the circumstances would not allow so easy an ascent, because the arches are circular; but if the middle arch, which is 38 feet high, had been made elliptical, then that height would have been reduced to 28.5 feet, that is, to three fourths of the present height; this would have diminished the height of the bridge by 9.5; and besides, one fourth of the masonry contained in the arches would thereby have been saved, which methinks would have been a sufficient inducement to recompence the little more trouble required to make an elliptic arch instead of a circular

one.

The width commonly allowed to small bridges is 30 feet; but in large ones near great towns, these 30 feet are allowed clear for horses and carriages, besides a banquet

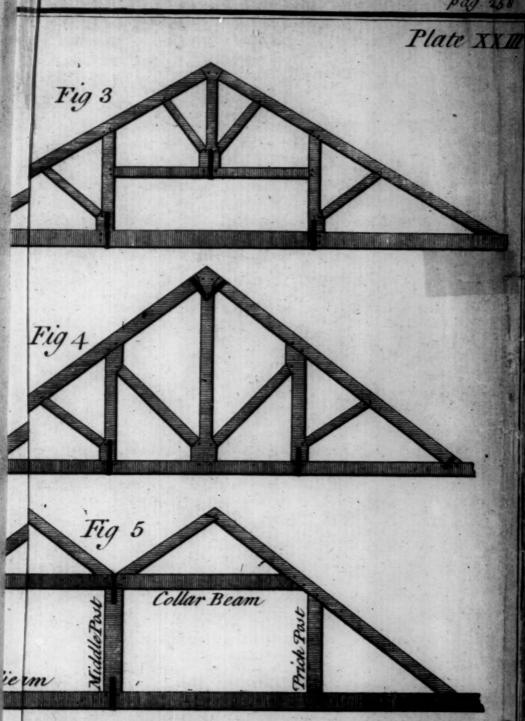
banquet at each fide for foot passengers of 6 to 9 feet each, raised about a foot above the common road; the parapet walls on each fide are about 18 inches thick, and four feet high; the generally project the bridge with a cornish underneath; sometimes ballustrades of stone or iron are placed upon the parapet as at Westminster; but this is only practifed where a bridge of a great length is made near the capital of a country.

The ends of bridges open from the middle of the two last arches with two wings making an angle of 45 degrees with the rest, in order to make their entrance more free and easy; these wings are supported by the same arches of the bridge next to them being continued in the same manner of an arch, of which one pier is

much longer than the other.

We have before determined the length of the keyflone, but faid nothing of the others towards the fpring of the arch; which were formerly made all of the fame length, and the rest of the front-walls finished with horizontal courses up to the cordon, and the spandrels or interval between the arches filled with rubble-stones without mortar; but now the joints of the arch-stones are continued quite up to the cordon, and the loofe stones between the arches on the infide are laid in the direction of the fame joints: this way of finishing the courses of the stones, both without and within, is certainly preferable to the former: but the best and only true method is, to form the outfide courses, in the manner just now mentioned, and in the inside, the arch-stones continued so as to form the curve, whose construction has been given in the last problem of the fecond fection, part the first; this being done, and the stones so far laid in mortar, they will be in equilibrio with each other, as has been shewn in that section; the rest may be filled up with loose stones having proper bonds as usual.

As the construction of this exterior curve is so easy its execution can admit of no difficulty; but because



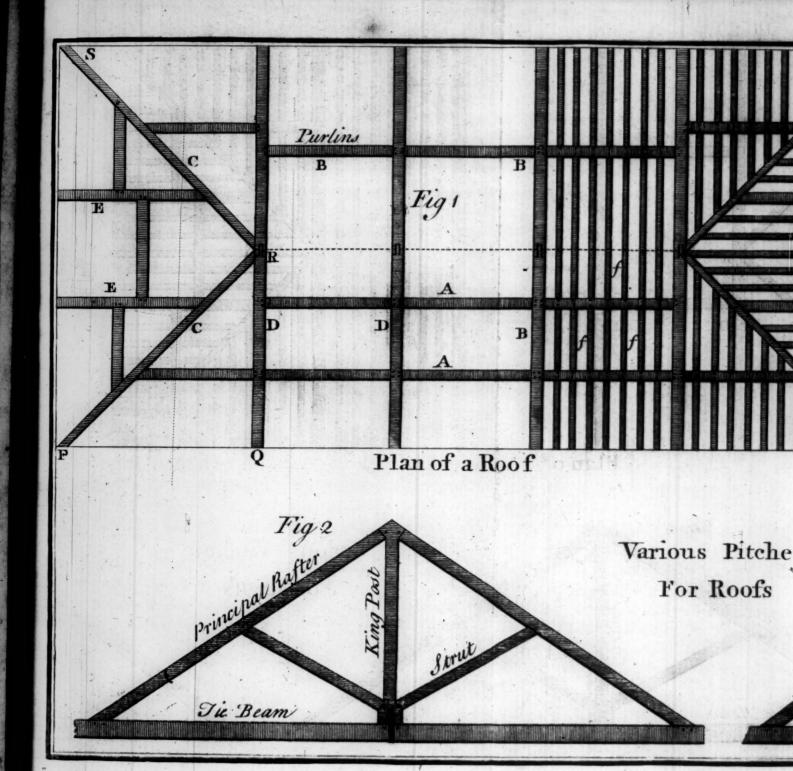
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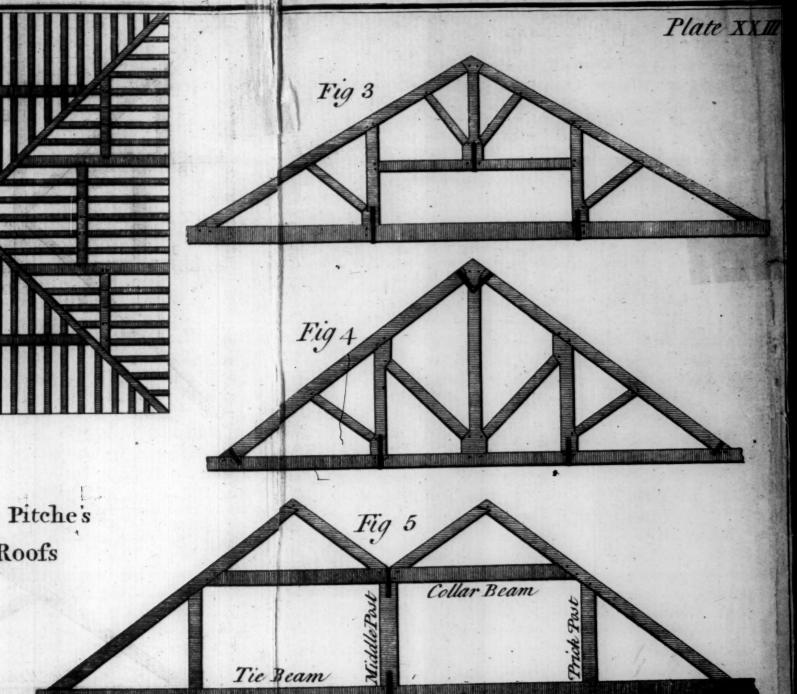
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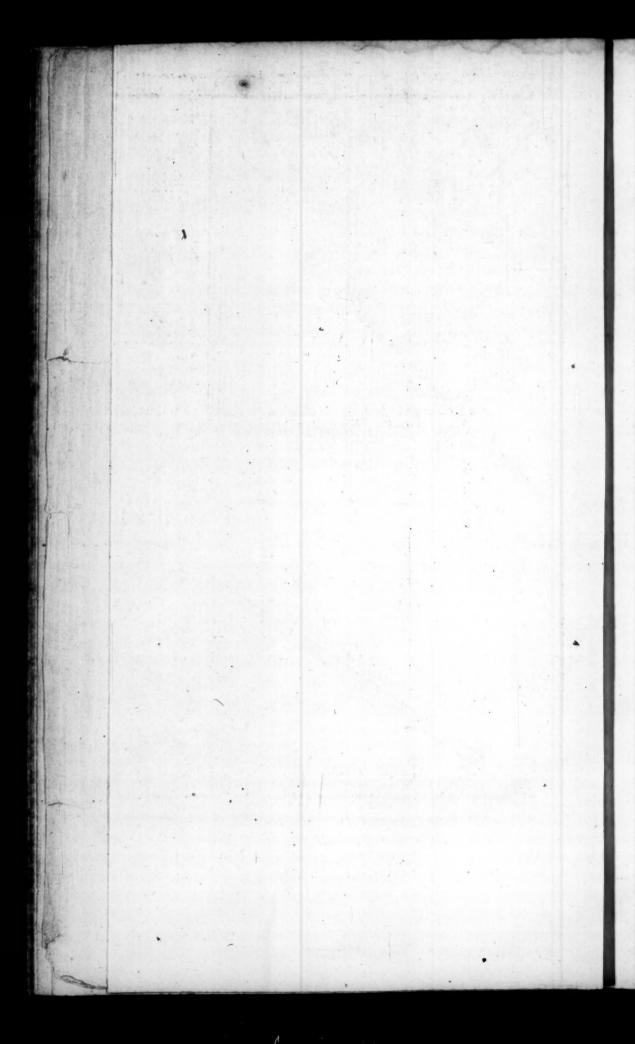
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we have not given that when the interior curve is an ellipsis, and we have proved that curve to be the best and only one to be used in bridges, we must beg leave to refer the reader to the fifth fection of the third book of our mathematical treatife, where it is given; it was

through overfight omitted in this work.

When the upper part of the bridge is finished with stones in the manner mentioned above, so as to form one continued curvilinear furface, a bed of fand and gravel is laid all over it, of about 6 feet deep, and then finished with paving the middle passage, or with coarse gravel, and the banquets are covered with flat stones for the foot passengers.

The fpring of the arches should begin at low-water mark, that is, that of the middle or greatest, the rest are raifed fomewhat higher, fo as to make the upper part of the bridge of the proposed descent; but in a situation where the water swells very high in some particular season of the year, regard must be had to that, and

the arches must be raised accordingly.

The first figure of plate XXIV. is the elevation of a bridge with elliptic arches, the fecond is the plan, and the third a fection through the middle of the arch next to the abutment; the arches are 75 feet wide, the piers 12 high, and 15 broad; the angles at the extremities are right ones, and reach from the bed of the river quite up to the top of the parapet, where they form recesses for passengers to retire into upon occasion; but the foundation up to the bed of the river is rectangular, for reasons mentioned hereafter. The section shews the wings of the bridge in front, and how the arch turns in that place.

We have thus given all the dimensions of the several parts of stone bridges (for the most part deduced from a well-afferted theory, and therefore may be depended upon with more fecurity than those given by other authors) and which are to be necessarily known before the building of a bridge is undertaken; we shall now

fhew how to proceed in the execution from the beginning of laying the foundation to the entirely finishing of the work.

How the work is to be carried on.

As the laying the foundation of the piers is the most difficult part of the whole work, it is necessary we should begin with an easy case, that is, when the depth of the water does not exceed 6 or 8 feet; and then proceed to those which may happen in a greater depth of water.

One of the abutments with the adjacent piers is inclosed by a dyke called batardeau by the French, of a fufficient width for the work, and room for the workmen; this batardeau is made by driving a double row of piles, whose distance is equal to the depth of water, and the piles in each row are 3 feet from each other; they are fastened together on the outside by bonds of 6 by 4 inches; this being done, frames of about 9 feet wide are placed on the infide to receive the boards, which are to form the inclosure, the two uprights of these frames are two boards of an inch and half thick, sharpened below to be driven into the ground and fastened together by double bonds, one below, and the other above, each separated by the thickness of the uprights; these bonds serve to slide the boards between; after these frames have been driven into the ground as hard as can be, then the boards themselves are likewise driven in till they reach the firm ground underneath.

Between every two piles tie beams are fastened to the bonds of the piles to fasten the inside wall to the outside one; these tie-beams are let into the bonds and bolted to the adjacent piles: This being done, the bottom is cleared from the loose sand and gravel, by a machine like those used by ballast-heavers; and then well-prepared clay is rammed into this coffer very tight and firm, to prevent the water from oozing through.

Sometimes

Sometimes these inclosures are made with piles only driven close to each other, at others the piles are notched or dove tailed one into the other: but the most usual method is to drive piles with grooves in them, 5 or 6 feet distant from each other, and boards are let down between them.

This being done, pumps and other engines are used to draw the water out of the inclosure, so as to be quite dry; then the soundation is dug, and the stones are laid in the same manner, and with the same precautions as have been mentioned in respect to those of a fortress: observing to keep some of the engines always standing, in order to draw out the water that may ooze through the batardeau.

The foundation being cleared, and every thing ready to begin the work; a course of stones is laid, the outside all round with the largest stretchers and headers that can be had, and the inside silled with ashlers well jointed, the whole laid in terrass mortar: the facings are crampt together, and set in lead; and some cramps are also used to fasten the facings with the inside. The same manner is to be observed throughout all the courses to the height of low-water mark; after which the facings alone are laid in terrass mortar, and the inside with the best of the common fort.

The extent of the base of the foundation does not so much depend on the bigness of the piers as on the whole weight of the superstructure, which methinks has not always been so much considered as should have been done; for it is said, that every course should project about a foot beyond that which is next above it from the height of low water mark, whether the bridge be high or low, the arches circular or ellipsic: but as every pier supports two half arches together with the weight of the stones laid between the hanches; the base ought to be regulated accordingly, as likewise in proportion to the height of the pier. When the foundation is carried to the height of low-water mark, or to

the height where the arches begin, which ought to be either thereabout or at most two feet above it when the arches are elliptical; then the shaft or middle wall is to be carried up nearly to the height of the arches, and there left standing till all the piers are finished, in order that the masonry may be sufficiently dry and settled be-

fore the arches are begun.

As the piers end generally with an angle at each end, it is customary to lay the foundation in the same manner, which is not so well as to continue the base rectangular quite to the ends of the piers, and as high as low-water mark; both because the foundation becomes then so much broader, and also because the water will not be able to get under it: for when the current sets against a stat surface, it drives the sand and mud against it, so as to cover it entirely; whereas if a sharp edge be presented to the stream, it carries every thing away, and exposes the foundation to the continual action of the water, which in course of time must

destroy it.

The piers being all finished, and the masonry well settled; the next thing to be done is to frame and fix the centers, which ought to be so folid and strong as to be able to support the great weight of the arches; as their construction is commonly known by workmen, and as those made use of at Westminster-bridge will be explained by Mr. Labely himself, we shall say no more of them than to observe, that they are fixed at the ends upon the projection of the foundation; and when the arches are very large they are supported in the middle by piles, and they must be raised by means of iron wedges about 3 inches higher than the arches are intended to be, in order to allow for the fettling of the masonry, these wedges by being loofened gradually ferve to eafe the center, so that it may only just touch the arch, and so facilitate the taking it quite away when the masonry is fufficiently fettled.

The

The French engineers fix thin boards on each fide with the directions of the joints marked upon them, for the conveniency of working with more speed; this appears to be very useful, especially when the arches are elliptical; they have patterns besides for every joint, in order

to cut the stones in a proper manner.

These preparations being made, the stones of the first course are crampt together, as also all those of every fifth course quite up to the key-stones. All the stones are to be laid in good strong mortar, not very thick, so that they may lay as close as possible, and cause but little settling: the arch being compleated, the center is eased by means of the wedges, but lest standing till the next arch is sinished; then it is taken away and made sit to serve for some other arch; so that there are not above three centers required to compleat the bridge.

After the intervals between the arches are filled up with stones laid in a regular manner without mortar, and the gravel is laid over them; two drains or gutters are made length-ways over the bridge one on each side next to the foot-path, of about 6 feet wide, and a foot deep; which, being filled with small pebble stones, serve to carry off the rain-water that falls on the bridge and to prevent its filtering through the joints of the arches, as

often happens.

If the same precaution's were used here, as have been above recommended to prevent water from penetrating through arches constructed under ground, I should imagine that this would be much better than the method commonly practised: for when the water passes through the joints of the arch-stones, as it does at Westminster bridge, it has an ill effect to the eye, because those stones that are wet look of a black colour, different from the rest.

How to build in water with COFFERS.

The former method of laying the foundation by means of batardeaus is very expensive and often meets with great difficulties: for when the depth of water is 8 feet or more, it is scarcely possible to make the batardeaus so tight as to prevent the water from oozing through them; and in that case, the number of engines required, as well as the hands to work them, become very expensive; and if part of the batardeau should break by some extraordinary wind or tide, the workmen would be exposed to very great danger.

Therefore the next and best method is to build with coffers, when it is practicable, such as were used at Westminster bridge. Since Mr. Labely promises to give a particular account of their construction, and the manner in which they were used, we shall here mention some sew things only, referring the reader for a fuller description of them to this gentleman's work, a part of which has been published since the bridge was sinished.

The height of water was 6 feet at a medium when lowest, and the tide rose about 10 feet at a medium also; so that the greatest depth of water was about 16 feet; at the place wherefone of the piers of the middle or great arch was to be, the workmen began to drive piles of about 13 or 14 inches square, and 34 feet long, shod with iron, so as to enter into the gravel with more eafe, and hooped above to prevent their splitting in driving them; these piles were driven as deep as could be done, which was 13 or 14 feet below the furface of the bed of the river, and 7 feet distant from each other, parallel to the short ends of the pier, and at about 30 feet distant from them; the number of these piles was 34, and their intent to prevent any vessels or barges from approaching the work; and in order to hinder boats from passing between them, booms were placed so as to raise and fall with the water.

This

This being done, the ballast-men began to dig the foundation under the water, of about 6 feet deep, and 5 wider all round than the intended coffer was to be, with an easy slope to prevent the ground from falling in; in order to prevent the current from washing the sand into the pit, short grooved piles were driven before the two ends and part of the sides, not above 4 feet higher than low-water mark, and about 15 feet distant from the coffer: between these piles, rows of boards were let into the grooves down to the bed of the river and fixed there.

The bottom of the coffer was made of a strong grate, confifting of two rows of large timbers, the one long-ways and the other cross-ways, bolted together with wooden trunnels, ten feet wider than the intended foundation. The fides of the coffer were made of fir timbers laid horizontally close one over another, pinned with oaken trunnels, and framed together at the corners, excepting at the two falient angles, where they were fecured with proper irons, fo that the one half might be loofened from the other if it should be thought necessary; these sides were lined on the inside as well as on the outfide with three inch planks placed vertically; the thickness of those sides was 18 inches at the bottom, reduced to 15 above, and they were 16 feet high; besides, knee-timbers were bolted at the angles, in order to fecure them in the strongest manner. The fides were fastened to the bottom by 28 pieces of timber on the outfide, and 18 within, called straps, about 8 inches broad, and 3 or 4 inches thick, reaching and lapping over the ends of the fides; the lower part of these straps had one side cut dove-tail fashion, in order to fit the mortifes made near the edge of the bottom to receive them, and were kept in their places by iron wedges; which being drawn out when the fides were to be taken away, gave liberty to clear the straps from the mortifes.

Before

Before the coffer was launched, the foundation was examined, in order to know whether it was level; for which purpose several gauges were made, each of which confifted of a stone of about 15 inches square, and 3 thick, with a wooden pole in the middle of about 18 feet long. The foundation being levelled and the coffer fixed directly over the place with cables fastened to the adjacent piles; the masons laid the first course of the stones for the foundation within it, which being finished, a fluice made in the fide was opened near the time of low-water; on which the coffer funk to the bottom; and if it did not fet level, the fluice was shut, and the water pumpt out, so as to make it float till fuch time as the foundation was levelled; then the ma-Sons crampt the stones of the first course and laid a second, which being likewise crampt, a third course was laid: than the sluice being opened again, proper care was taken that the coffer should settle in its due place. The stone-work being thus raised to within two feet of the common low-water mark, about two hours before low-water the fluice \was flut, and the water pumpt out fo far as that the masons could lay the next course of stone, which they continued to do till the water was rifen fo high as to make it unfafe to proceed any farther; then they left off the work, and opened the fluice to let in the water; thus they continued to work night and day at low-water, till they had carried their work some feet higher than the low-water mark; after this the fides of the coffer were loofened from the bottom, which made tham float, and then were carried ashore to be fixed to another bottom, in order to serve for the next pier.

It must be observed, that the coffer being no higher than 16 feet, which is equal to the greatest depth of water, and the foundation being 6 feet under the bed of the river; the coffer was therefore 6 feet under water when the tide was in; but being loaded with three courses of stones, and well secured with ropes fastened

to the piles, it could not move from its place. By making it no higher much labour and expence were faved, yet it answered the intent full as well as if it had been

high enough to reach above the highest flood.

The pier being thus carried on above low-water mark, the masons finished the rest of it during the intervals of the tides in the usual way; and after all the piers and abutments were finished in a like manner, the arches were begun and compleated as mentioned before: the whole bridge was built in about seven years, without any accidents happening, either in the work or to the workmen, which is seldom the case in works of this nature.

It may be observed, that all the piers were built with folid *Portland* stone, some of them weighed four tons, the arch-stones were likewise of the same sort, but the rest of the masonry was finished with *Kentish rag stones*; and the paths for foot passengers were paved with *Purbec*, which is the hardest stone to be had in this country, ex-

cepting Plymouth marble.

This method of building bridges is certainly the eafieft and chapeft that can be thought of, but cannot be used in many cases: when the foundation is so bad as not to be depended upon without being piled, or the depth of water is very great, with a strong current and no tide, I do not see how it can then be practised. For if piles are to be used, it will be next to impossible to cut them off in the same level five or fix feet below the bed of the river, notwithstanding that saws have been invented for that purpose; because, if they are cut off separately it will be a hard matter to do it so nicely that the one shall not exceed the other in height, and if this is not done, the grating or bottom of the coffer will not be equally supported, whereby the foundation becomes precarious: neither can they be cut off all together; for piles are to be driven as far as the bottom of the coffer extends, which at Westminster bridge was 27 feet; the faw must have three feet play, which makes the total length of the faw 30 feet; now if either the water is deeper than it is there, or the arches are wider, the faw must still be longer; so that I leave the reader to judge whether this method be practicable or not, in any such like cases.

In a great depth of water that has a strong current and no tide, the coffers must reach above the water, which makes them very expensive, and unweildy to manage, as well as very difficult to be secured in their places, and kept steddy: so that there is no probability

of using them in such a case.

In some cases when there is a great depth of water, and the bed of the river is tolerably level, or can be made so by any contrivance, a very stronge frame of timber about four times as large as the base of the piers may be let down with stones upon it round the edges to make it sink: after fixing it level, piles must be driven about it to keep it in its place; and then the soundation may be laid in coffers as before, which are to be

kept steddy by means of ropes tied to the piles.

This method has frequently been used in Russia, as I have been assured by a gentleman who has seen it. Though the bed of the river is not very solid, yet such a grate, when once well settled with the weight of the pier upon it, will be as firm as if piles had been driven under the soundation; but to prevent the water from gulling under the soundation and to secure it against all accidents, a row of dove-tail piles must be driven quite round the grating; this precaution being taken, the soundation will be as secure as any that can be made.

The French engineers make use of another method in raising the foundations of masonry under water; which is, to drive a row of piles round the intended place, nearer to, or farther from each other, according as the water is more deep or shallow; these piles, being strongly bound together in several placed with horizontal tie-beams, serve to support a row of dove-tail piles driven

driven within them; when this is done, and all well fecured according to the nature of the fituation and circumstances, they dig the foundation by means of a machine with scoops, invented for that purpose, until they come to a solid bed of gravel or clay; or if the bed of the river is of a soft consistence to a great depth, it is dug only to about 6 feet, and a grate of timber is laid upon it, which is well secured with piles driven into the opposite corners of each square, not minding whether they exceed the upper surface of the grate much or little.

When the foundation is thus prepared, they make a kind of mortar called beton, which confifts of twelve parts of pozolano or dutch terrals, fix of good fand, nine of unflaked lime the best that can be had, thirteen of stone splinters not exceeding the bigness of an egg, and three parts of tile-dust, or cinders, or else scales of iron out of a forge: this being well worked together must be left standing for about 24 hours, or till it becomes so hard as not be separated without a

pick-ax.

This mortar being thus prepared, they throw into the coffer a bed of rubble stone not very large, and spread them all over the bottom as nearly level as they can; then they sink a box sull of this hard mortar, broken into pieces, till it comes within a little of the bottom; the box is so contrived as to be overset or turned upside down at any depth; which being done, the pieces of mortar soften and so fill up the vacant spaces between the stones; by these means they sink as much of it as will form a bed of about twelve inches deep all over: then they throw in another bed of stone, and continue alternately to throw one of mortar and one of stone till the work approaches near the surface of the water, where it is levelled, and then the rest is sinished with stones in the usual manner.

Mr. Belidor fays, in the second part of his hydraulics, vol. ii. pag. 188, that Mr. Melet de Montville having filled

filled a coffer containing 27 cubic feet, with masonry made of this mortar, and sunk it into the sea, it was there left standing for two months, and when it was taken out again, it was harder then stone itself. Where such mortar can be made, this method has certainly the advantage over all the others, not only in building the piers of bridges over deep rivers, but likewise in making piers for harbours, and in all other aquatic works; but before it is made use of, I would advise the engineer to make first a trial of his mortar; since works of this nature are of too great consequence to be carried

on without an absolute certainty of success.

We have hitherto mentioned fuch fituations only where the ground is of a foft nature; but where it is rocky and uneven all the former methods prove ineffectual; nor indeed has there yet been any one proposed that I know of, which might be used upon such an occasion, especially in a great depth of water; but as an engineer ought to know how to proceed upon all occasions, we shall therefore mention some few observations under-When the water is not fo deep but that the unevenness of the rock can be perceived by the eye, piles strongly shod with iron may be raised and let fall down by means of a machine, upon the higher parts, fo as to break them off piece by piece, till the foundation is tolerably even, especially when the rock is not very hard; which being done either this or any other way that can be thought of, a coffer is made without any bottom, which is let down and well fecured, fo as not to move from its place; to make it fink, heavy stones should be fixed on the outside; then strong mortar and stones must be thrown into it; and if the foundation is once brought to a level, large hewn stones may be let down so as to lie flat and even; by these means the work may be carried on quite up to the furface of the water.

But when the water is so deep, or the rock so hard as not to be levelled, the foundation must be sounded,

fo as to get nearly the risings and fallings; then the lower part of the coffer must be cut nearly in the same manner, and the rest finished as before. It must however be observed, that we suppose a possibility of sinking a coffer, but where this cannot be done, no method that I know of will answer; and therefore I leave it to the judgment and knowledge of the engineer employed upon such an occasion, in what manner he is to

proceed.

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Among the aquatic buildings of the ancients none appear to have been more magnificent than Trajan's bridge. Dion Cassius gives the following account of it: "Trajan built a bridge over the Danube, which in " truth one cannot fufficiently admire; for though all " the works of Trajan are very magnificent, yet this " far exceeds all the others: The piers were 20 in " number, of square stone; each of them 150 feet high " above the foundation, 60 feet in breadth, and distant " from one another 170 feet. Though the expence of this work must have been exceeding great, yet it becomes more extraordinary by the river's being very " rapid, and its bottom of a foft nature: where the " bridge was built, was the narrowest part of the river thereabout, for in most others it is double or treble "this breadth; and although on this account it became " fo much the deeper and the more rapid, yet no other of place was fo fuitable for this undertaking. The " arches were afterwards broken down by Adrian; but "the piers are still remaining, which seem as it were " to testify, that there is nothing which human inge-" nuity is not able to effect." The whole length then of this bridge was 1590 yards; some authors add, that it was built in one fummer, and that Apollodorus of Damascus was the architect, who left behind him a defcription of this great work. It is a great loss to the world that his description has not come down to us, since it would have shewn both how these works were carried on formerly

formerly and how far modern builders are inferior to the antients.

SECT. II.

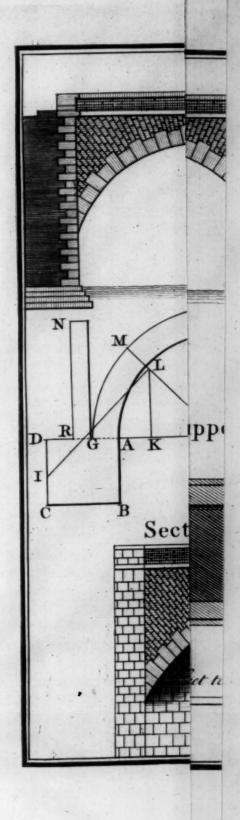
Of HARBOURS.

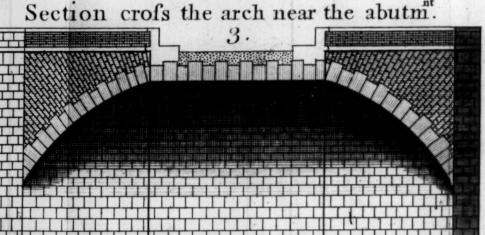
THE making and inclosing harbours with piers, fo as to refift the wind and waves for the prefervation of ships in stormy weather, is one of the most useful and necessary works that can be made in a trading nation, fince the fecurity of their wealth and power depends greatly upon it; for many thips have been cast away, and the lives of many people lost, for want of a secure harbour, which might have been saved for a moderate fum of money, had it been properly ap-

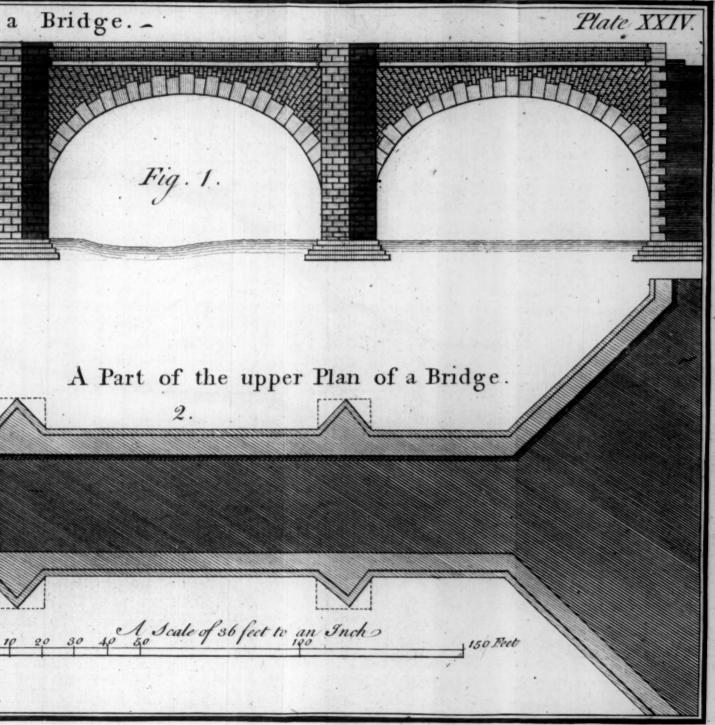
plied.

Though engineers are not generally employed here in England in such kind of works, yet it is properly their business; this may perhaps rather be owing to their want of skill in them to any thing else: but since fortreffes are generally built near the fea or navigable rivers for the security of trade, and this cannot be secured without building fafe harbours; therefore it ought to be the particular study of every young engineer, who is desirous of being useful to his country, or of distinguishing himself, to make himself master of this branch of business.

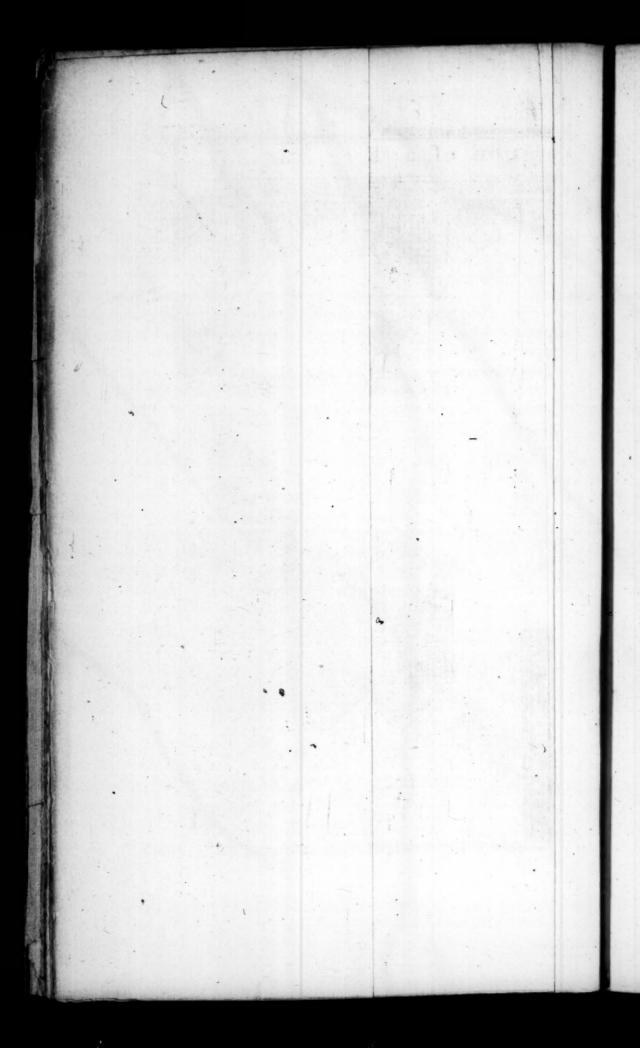
As it feldom happens that fuch works are carried on at home, he should attentively examine those harbours already executed, both at home and abroad, and take notice of their figure, fituation, entrance, wind and tide, whether the ships can go in with safety in foul weather, and out when favourable; whether it would have been better if the entrance had been made elfewhere; whether the piers are ftrong and folid, or want often to be repaired, and in general whether the harbour







J. Couse Soulp.



harbour answers in every respect the intention for which it was built.

He ought to get information from the inhabitants, workmen, or the builder himself, if he is alive; to know the reasons for making it of that figure, why the entrance is placed in that situation, how the foundations were laid, what accidents happened, how long it was in building, what number of hands were employed, and what the expences have been.

Having thus examined as many harbours as he could conveniently see, and having made himself acquainted with the manner of their building, he will be able to judge, when a new one is proposed, whether the situation is proper or not, and how it may be executed in the best and securest manner, together with what the

expences would nearly come to.

But before a young engineer enters upon practice, he should have a proper knowledge of the mathematics, especially of that part which treats of the mechanical powers and hydraulics, in order to know in what manner engines are constructed and applied to the several uses they are intended for; this he may obtain by consulting those authors who have written upon them, and by examining the engines themselves, to see if they answer the intention, or whether they might not be improved; or else, if others could not be invented of a different form, which would be more simple, and more expeditious.

In order to affift beginners, we shall set down here the principal enquiries to be made before a harbour is executed, the manner of laying the foundation, and how the works are to be carried on most securely, in the plainest and easiest manner that we could think of, and which has been approved of by most authors who

have treated of this subject.

The first thing to be considered is the situation, which may be some large creek or bason of water, in or near the place were the harbour is intended to be made.

made, or at the entrance of a large river, or near the fea; for a harbour should never be dug entirely out of dry land, unless upon some extraordinary occasions, where it is impossible to do otherwise, and yet a harbour is absolutely necessary; when a proper place is found, before it is fixed upon, it must be considered whether ships can lie there safe in stormy weather, especially when those winds blow which are most dangerous upon that coast; whether there be any hills, rising ground, or high buildings that will cover it; in these cases the situation is very proper; but if there be nothing already that will cover the ships, it must be observed whether any covering can be made at a moderate expence, otherwise it would be useless to build a harbour there.

The next thing to be considered is, whether there be a sufficient depth of water for large ships to enter with safety, and lie there without touching the ground, and if not, whether the entrance and inside might not be made deeper at a moderate expence; or in case a sufficient depth of water is not to be had for large ships, whether the harbour would not be useful for small merchantmen; for such a one is often of great advantage when situated upon a coast much frequented by small coasting vessels.

The place where the entrance is to be made ought to be well confidered; it ought to be such that the ships may enter in foul weather and go out when fair: for though ships may enter when in distress, yet if they cannot go out when the wind is fair to pursue their voyage and not to lose their market; such a harbour would not answer the end for which it was designed.

It is therefore necessary to consider well the current, tide, and winds, as also the banks of sand near about it; and to consult the masters of ships as well as the pilots who live thereabout, or frequent the coasts: they are better judges where the entrance should be than any body else; but if it should happen that they are divided

in their opinions, as it often is the case; it will be prudent not to determine the fituation of the entrance till part of the piers are built, and sufficient observa-

tions made, where it will be most convenient.

When a fituation has been found that has all or most of these requisite advantages, an enquiry is to be made concerning the materials to be used in building the piers, where they are to be had; if upon the fpot, near at hand; or when at a distance, whether they are to be brought by land or water carriage, or partly one way and partly the other; their prime cost must be known, the expence for bringing them to the spot, the time required, and the expence of the workmanship to make them ready for use.

All these preparative enquiries being made, the form or figure of the harbour must be determined in such a manner that the ships which come in when it is stormy weather may lay fafe, and fo as there may be fufficient room for as many as pass that way: the depths of water where the piers are to be built, must be taken at every ten, fifteen, or twenty feet distance, and marked upon piles driven here and there, in order that the workmen

may be directed in laying the foundation.

This being done, it must be considered what kind of materials are to be used, whether stone, brick, or wood: when stones are to be had at any moderate price, they ought to be preferred, because the work will be much stronger, more lasting, and need fewer repairs than if made with any other materials: but when stones are fcarce, and the expence becomes greater than what is allowed for building the harbour, the foundation may be made of stone as high as low-water mark, and the rest finished with brick. If this manner of building should still be too expensive, wood must be used; that is, piles are driven as close as is thought necessary, which being fastened together by cross-bars, and covered with strong oaken planks, form a kind of coffer, which is filled with all kinds of stones, chalk, and shingles,

shingles, as will be explained more at large hereafter.

The materials being fixed upon, an estimate is made of the expences; the number of hands to be employed at a time is determined, so as they may conveniently work without interfering with one another; and from thence it may be nearly computed what time will be

required for compleating the whole work.

The manner of laying the foundation in different depths of water, and in various foils, requires particular methods to be followed: when the water is very deep, the French throw in a great quantity of stones at random, so as to form a much larger base than would be required upon dry land; this they continue to within 3 or 4 feet of the surface of the water, where they lay the stones in a regular manner, till the foundation is raised above the water; they then lay a great weight of stones upon it, and let it stand during the winter to settle, as likewise to see whether it is firm, and resists the force of the waves and winds; after that they sinish the super-structure with large stones in the usual manner.

As this method requires a great quantity of stones, it can be practised but in a few places, where stones are in plenty; and therefore the following one is much preferable. A coffer is made with dove tail piles of about 30 yards long, and as wide as the thickness of the foundation is to be; then the ground is dug and levelled in the manner described in the last section; and the wall is built with Beton mortar, as has been described in the same section.

As foon as the mortar is tolerably dry, those piles at the end of the wall are drawn out, the side rows are continued to about 30 yards farther, and the end inclosed; then the foundation is cleared, and the stones laid as before. But it must be observed, that the end of the foundation sinished is lest rough, in order that the part next to it may incorporate with it in a proper manner; but if it is not very dry it will incline that

way of itself, and bind with the mortar that is thrown in next to it; this method is continued till the whole

pier is entirely finished.

It must likewise be observed, that the piers are not made of one contined solid wall; because in deep water it would be too expensive; for which reason, two walls are built parallel to each other, and the interval between them is silled up with shingle, chalk, and stone: As these walls are in danger of being thrust out or overset, by the corps in the middle, together with the great weight laid at times on the pier, they are tied or bound together by cross-walls at every 30 or 40 yards distance, by which they will support each other in a firm and strong manner. For want of these cross-walls it has happened, not many years ago, that the walls of a work were overset for the space of some hundred yards.

If such mortar can be made as what the French call Beton, there can scarcely be found a better method than that above for laying foundations in deep water, and it may be used upon all occasions; but as such mortar is not every where to be had without great expences, I imagine that common terrass mortar, mixt with small stones, and some cinders if to be had, will answer the purpose as well; but the engineer, who is to carry on the work, ought to make trial of it before

he uses it.

If the foundation be bad to a great depth, I would fink it only about 4 feet below the bed of the river; and lay a strong grate of timber, as in those of the piers of a bridge; but if it should be rocky, a coffer must be made without a bottom, and the under part cut nearly with the same risings and fallings, according to the manner mentioned in the last section.

In a country where there is a great plenty of stones, piles may be driven in as deep as they will go, at about two or three feet distance, and when the foundation is funk and levelled, large stones may be let down, which

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will bed themselves; but care must be taken to lay them close, and so as to have no two joints over each other; and when the wall is come within reach, the stones must be crampt together.

Another method practifed, is to build in coffers much after the same manner as has been done in building the piers of Westminster-bridge; but as in this case the ends of the coffers are left in the wall, and prevent their joining so well as to be water-tight, the water that penetrates through and enters into the corps, may occasion the wall to burst and to tumble down. Another inconveniency arising from this manner of building is, that as there are but sew places without worms, which will destroy wood wherever they can find it, by their means the water is let into the pier, and consequently makes the work liable to the same accident as has been mentioned above.

To prevent the incoveniencies of this method, I would take the wood away, and joggle the ends of the walls together with large flones, and pour terrass mortar into the joints; when this is done, the water between the two walls may be pumpt out, and the void space filled up with stone and shingle as usual: or if these joggles cannot be made water-tight, some dovetail piles must be driven at each end as close to the wall as can be done, and a strong sail-cloth put on the outside of them, which, when the water is pumpt out, will stick so close to the piles and wall, that no water can come in. This method is commonly used in Russia, as I have been informed.

Plate XXV. In order to understand clearly the method of building piers, we have given the plan and section of one of the walls, in the first figure, such as had been proposed for inclosing a harbour, upon a chalky foundation: the water is but 6 feet high when lowest, and rises to 24 when the tide is in. The manner proposed for building the piers, was to dig the foundation about two feet deep, which is sufficient for such

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a ground, and to fink large blocks of stone of about 3 feet high, which could have eafily been crampt together at 3 or 4 feet under water; then to lay another course of large stones over the first, and to cramp them as before; the same thing was to be done, till the wall was carried about two feet above low-water mark: or if this method of laying the foundation was not approved of, to lay it in coffers in the manner mentioned above.

It was faid, that the funds allowed for building the harbour were not fufficient to make the piers entirely of stone; for which reason, the rest was to have been continued with hard bricks, fuch as are called clinkers, to about 8 feet high; then a course of stones was to be laid of a foot high and crampt together; after this bricks were to be laid again to the same height as before, and then another course of stone; this was to have been continued quite up to the entire completion of the pier.

The stone foundation being 8 feet high, that is, from two feet under the bed of the water to low-water mark; and from thence to the top being 23 feet; therefore the infide wall is five feet higher than high-water mark; and as the outfide wall has a parapet of 5 feet high, and 3 or 4 thick; this wall is ten feet higher than the water when the tide is in; which height was thought neceffary, in order to cover the people standing there, from the water, because the waves rise very high in that

place, at certain times of the year.

The walls were to be 28 feet distant from each other. five feet thick above, and the base of the slope one fifth of the height; which would have made the thickness of the piers 34 feet above, besides the parapet, which takes up 4, and 50 near the bottom of the water. every 30 feet distance was to be made a cross or tie-wall. of three feet thick, to bind the two walls together; this distance may be greater near the shore, where the waves have not so great a force as farther from it; and

to fave trouble as well as expences, these cross-walls were to be built with low arches upon piers of four feet long, beginning at low-water mark, as may be

feen in the plan and fection.

The thickness of a pier depends on two considerations; it ought to be both fuch as may be able to refift the shock of the waves in stormy weather, and also to be of a sufficient breadth above, that ships may be laden or unladen whenever it is thought necessary. Now because the specific gravity of sea-water is about one half that of brick, and as 2 to 5 in comparison of stone, and fince the pressure of stagnated water against any furface is equal to the weight of a prism of water whose altitude is the length of that furface, and whose base is a right angled isosceles triangle, each of the equal fides being equal to the depth of the water, therefore a pier built with bricks, whose thickness is equal to the depth of the water, will weigh about four times as much as the pressure of water against it: and one of stone of the same breadth about 6 times and a quarter as much. Now this is not the force to be confidered, fince this pressure is the same within as without the pier; but it is that force with which the waves strike against the piers, and that depends on the weight and velocity of the waves, which can hardly be determined; because they vary according to the different depths of water, the distance from the shore, and according to the tides, winds, and other causes. Consequently the proper thickness of the piers cannot be determined by any other means than by experience.

Practitioners suppose, that if the thickness of a pier is equal to the depth of the water, it is sufficient; but for a greater security they allow 2, 3, or 4 feet more; this might probably do, if piers were built with solid stones crampt together; but as this is hardly ever the case, and on the contrary, as the inside is filled up with shingle, chalk, or other loose materials, their rule is not to be depended upon: besides it makes the

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space above too narrow, for lading and unlading the ships, unless in a great depth of water; so that it does not appear that their method can be followed excepting in a very few cases where the water has but very little motion.

The reader will easily perceive, that the plan and section represented in this plate, may serve for a pier built either of all stone or brick, or else with both mixt together; by observing only to make the walls something stronger when they are made with bricks, than when of stone. When stone can be had, no other materials should be used, because they being of a larger bulk than brick, will resist better the waves by their own weight, till such time as the mortar is grown hard; for after this is effected, brick will resist better against the action of sea-water than soft stones.

The wall must be built with terrass mortar from the bottom to the height of low-water mark, and the rest sinished with cinder or tile-dust mortar, which has been found sufficiently good in those places where the wall is wet and dry alternately. The upper part of the pier should be paved with slat hewn stones laid in strong mortar, in order to prevent any water from penetrating into the pier: iron rings ought also to be fixed here and there at proper distances, to fasten the ships, and prevent them from striking against the pier when agitated by the waves.

At the mouth of the harbour the piers should be terminated with plat-forms, or forts, to place guns there, in order to defend the entrance, in case of necessity. Sometimes piers are built so large as to place store-houses upon them, especially in sea-port towns, where seets are fitted out: this has been done at Toulon, about the harbour of the royal navy, whereby the ships are covered from the wind, as well as from being seen from without; so that a seet may be fitted out in a private

manner.

Wooden

Wooden fenders or piles should be driven at the inside close to the wall, and crampt to it with iron, to
prevent the ships from touching them, and from being
worn by their continual motion. Where the sea breaks
against the piers with great violence, breakers should
be made at proper distances; that is, two rows of piles
are driven nearly at right angles to the piers for the
length of about 12 or 15 feet, and at about 8 or 10
feet distant from each other; and then another to join
the two former; these piles being covered with planks,
and the inside being filled with shingle and rubblestones, then the top is paved with stones of about a foot
in length, set long-ways to prevent the waves from
tearing them up. This precaution is absolutely necessary
where the water rushes in very strongly.

The section represented here, contains 1035.6 cubic feet of masonry, for every foot in length, and 834 cubic feet of rubbish or shingle to fill up the inside; so that knowing the length of the piers, and the price of the materials and workmanship, the whole expence for building the piers will be easily known; barring accidents, which unavoidably will happen in all works of this kind, and for which the French generally allow one

fixth part of the expences computed.

When it happens that stones are not to be had, without great expence, or the importance of the harbour is not much; then piers are built with timber, such as that at Dover, and in many other places. The plan and section represented by the second figure may in such a case be aptly applied; the breadth above of the section is 30 feet, the base of the slope of the outward piles one sixth part of the height, which is here the same as in the former section, that is, 29 or 30 feet: the piles are about 14 inches square, the cross-beams a from 10 to 12, and the tie-beams b, 8 by 10. These frames are from 12 to 15 feet distant from each other, and three piles are to be driven between them, as may be seen by the plan; there are besides two rows of short piles on

each fide of the pier, five feet distant from the long ones; and which reach no higher than low-water mark.

The reason for driving these short piles is, that being always under water they will not decay, and nothing will hurt them, excepting worms; so that when the long ones, which are exposed to wet and dry, are decayed, the foundation remains sound and firm; by which means it will be easy to repair that part of the pier above low-water mark, whenever there is any occasion for it. And to secure the foundation still better, dove-tail piles of about 6 inches thick, are to be driven all round, and strongly fastened together with timbers, one above to receive the heads, and others on the outside.

The fides of the piers are to be covered with good oaken planks of about 4 or 5 inches thick, fastened to the tie-beams b, with wooden trunnels; or else, these planks may be placed on the inside of the tie-beams b, which, in my opinion, is better, because the pressure of the shingle and rubble-stones with which the inside of the pier is filled, will not be able to loosen the planks, as it might do, when they are fastened on the outside.

It is faid, that when the planks are fastened on the inside, they cannot be easily repaired when there is occasion for it; but this objection is inconsiderable, in respect to the advantage arising from this position; for the rotten plank being taken away, a new one may easily be slipped into it's place, between the tie-beams b, and the shingle: and if they cannot be fastened with wooden trunnels, it may be done with iron nails. The planks must reach about 4 feet above the upper surface of the pier, and be secured with proper timbers, so as to form a kind of parapet on each side, in order to prevent the people, standing there, from being wetted by the waves in stormy weather.

This frame is the most simple, and the most natural that we could think of; and yet as strong, in my opinion, as can be desired to resist the action of the waves let them be ever so great: it is true, that most of the

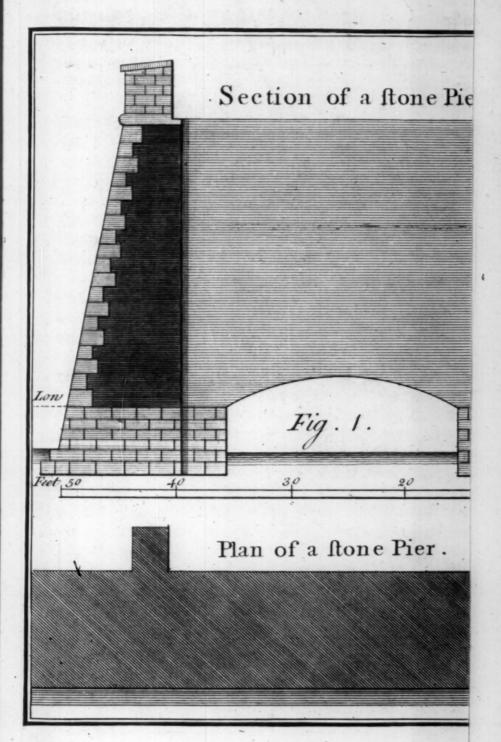
workmen

workmen will think it insufficient, as having no braces, of which they are so fond, that they think no work well secured without them; but as I do not esteem

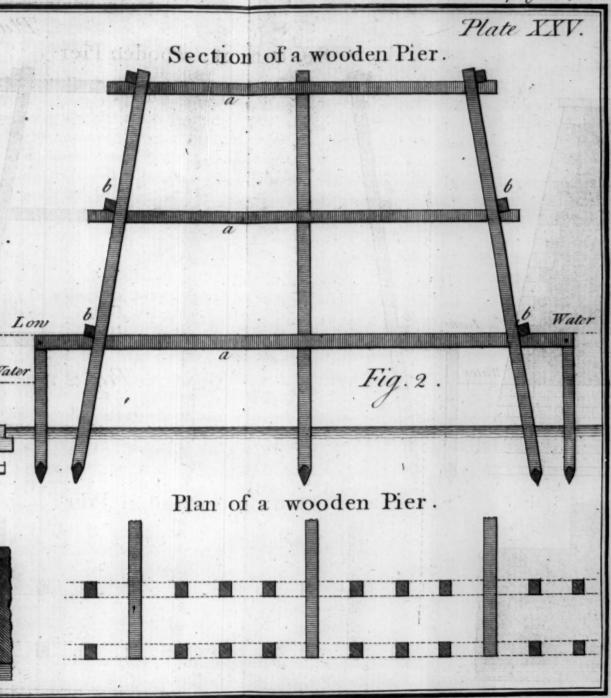
them necessary, I have omitted them here.

In those wooden piers I have seen, there was no base made with short piles, such as are represented in the second sigure; for the long piles reached from top to the bottom, and no dovetail piles were driven to secure the foundation, as far as I could find; but since such works ought to be made in the most secure manner, and so as not to want continual repairing; I would advise the directors of them, to consider well the nature of the situation, as well as the importance of the harbour, before they form a scheme for building the piers.

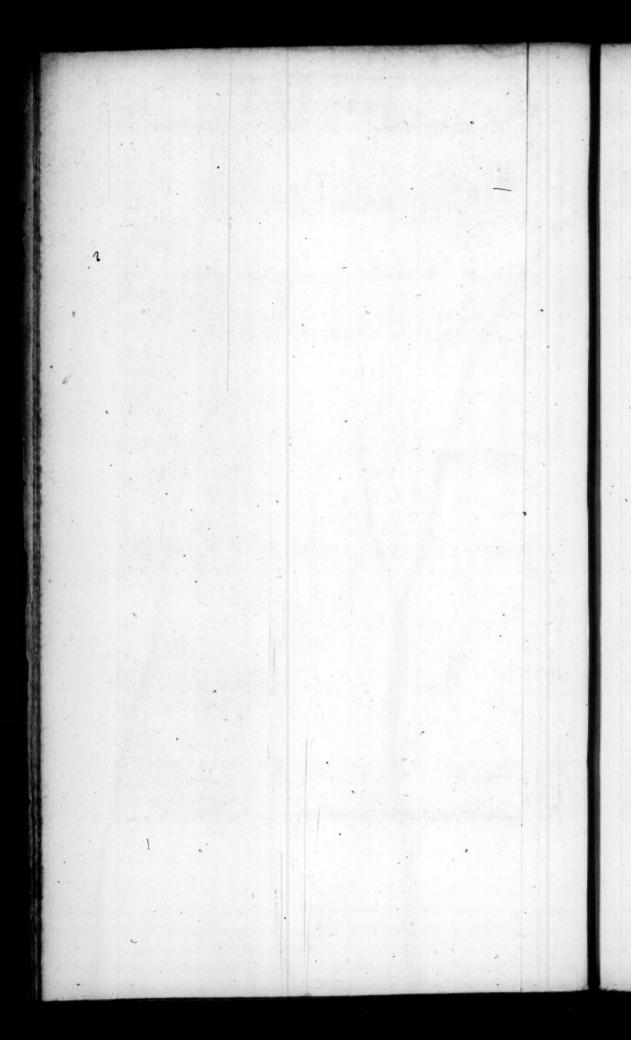
What has been faid here in regard to the building of piers for harbours will equally ferve for that of quays, and all other works made in water; it must only be obferved, that as quays are often loaded with very great weights, the wall must be made much stronger than those of ramparts, which support the pressure of earth only. But to give some rule whereby the reader may be directed, I imagine that, if the thickness be treble that of the wall of a rampart of the same height, it will be sufficient: thus if the height of the quay be 10 feet, and the base of the slope one fixth of the height; by trebling the height 1.5 feet, found in table the first for the thickness above of a wall of the same height, we get 4.5 feet for the thickness above of the said wall. To fecure these walls yet better, piles are driven on the infide about 20 feet distant from the wall, and about 15 feet from each other; the heads of which are tenoned into a beam, and others laid across are let into this beam at one end, and at the other going through the wall are fixed to the fenders on the outfide with iron straps bolted into these beams.



B



J. Couse Sculp .



SECT. III.

Of SLUICES and AQUEDUCTS.

SLUICES are made for various purposes; such as to make rivers navigable; to join one river to another, which is higher or lower, by means of a canal; to rise inundations upon particular occasions, or to drain spots of ground that are overflown by high tides: they are also made in fortresses, to keep up the water in one part of the ditches whilst the other is dry; and to raise an inundation about the place when there is any apprehension of being attacked.

Sluices are made different ways, according to the uses they are intended for; when they serve for navigation, they are shut with two gates presenting an angle towards the stream: when they are made near the sea two pair of gates are made, the one to keep the water out and the other in, according as occasion requires; in this case, the gates towards the sea present an angle that way, and the others the contrary way; the space inclosed by these gates is called Chamber.

When fluices are made in the ditches of a fortress to keep up the water in some parts, instead of gates, shutters are made, so as to slide up and down in grooves; and when they are made to raise an inundation, they are then shut by means of square timbers let down into cullises, so as to lie close and firm.

Particular care must be taken in the building of a sluice, to lay the foundation in the securest manner that is possible; to lay the timber grates and sloors in such a manner that the weather cannot penetrate through any part, otherwise it will undermine the work, and blow it up, as it has sometimes happened: Lastly, to make the gates of a proper strength, in order to sup-

port the pressure of the water, and yet to use no more

timber than what is necessary.

As a general construction is much preserable to particular ones, we shall follow the example of Mr. Belidor, who is the first that gave one for sluices; but before this can be done, it is necessary to know its width, and the depth of water it is to contain, and from thence the dimensions of the several parts are determined, as will be shewn hereafter.

When fluices are made in a canal, or navigable river, their width will be known from the fize of the veffels that are to pass through them, as well as the depth of water they require; when they are made in a fortress to pen up the water in one part, and to keep the other dry, their width is determined by the quantity of water that is to pass through them in a certain time: When they are near the sea, or a river where there is a tide, and they are to keep up the water at a certain height; their width and depth are also determined from the nature of the situation; and in general, the width and depth of a sluice is always known from its situation, and the use it is intended for.

This being premised, we shall give a general construction of a great sluice with two pair of gates, in such a manner as to be applicable to any particular case, provided a proper allowance be made for the various circumstances that may happen, in regard to their use and situations, which may change some of the parts,

as shall be mentioned in its proper place.

To construct the PLAN of a SLUICE.

Plate XXVI., Suppose half the width OC to be divided into fix equal parts, or the whole into twelve; these parts serve for a scale, whereby the dimensions of the work are determined: through the point O, draw the line AB at right angles to OC; take OB on one side of the point O equal to 30 of these parts, or, which is the same, equal to two widths and a quarter; through

the points A, B, draw the lines A R, B S at right angles to A B; let the lines passing through the point C, and parallel to A B, meet these last lines in M, Q; then if M N, P Q be taken each equal to parts, and each of the lines M R, Q S equal to six, the lines N R and P S will determine the wings of the sluice, and N P the body. If the lines A R, B S be produced so as the parts R V, S T are each 6; they will determine the faces.

The part B O of the length exceeds the other part O A by one fourth of the width, because we suppose a turning bridge is to be placed on that side for a communication from one side of the sluice to the other; but when there is no occasion for such a bridge, O B is made no longer than O A; and then the total length will be but four times and a half the width, which is esteemed by Mr. Belidor the best length that can be

given to a great fluice.

To determine the chamber and the polition of the gates, take OD, OL, each equal to four parts, and draw the lines DG, LH parallel to OC; then if the lines GK, HI be drawn fo as to make the angles DGK, LHI, each of 35 degrees, and 16 minutes, that polition will be the best that can be given, by art. 566 of our Elements of Mathematics; or, because a linear construction is preferable to that by angles, the position of the lines GK, HI, is determined in the same manner as the line AE in fig. 7, plate the fifth, page 90, of this work.

The cavities z, y, are a foot each way in large fluices, and but 9 inches in middling ones; they serve for letting down square timbers to form a batardeau on each side, in case the gates or floor want to be repaired.

The recesses Ga, Hb in the wall, are made to receive the gates when open, and are of such a depth that they may be slush with the wall, and not make that part narrower than the rest of the sluice.

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The thickness of the wall from N to P is equal to four fifths of the depth of water, the parts R N R, P S, three fifths, and at V, T two fifths. The counterfort W, is determined by producing the lines LH, DG, and projects beyond the wall by one fourth of the width of the fluice.

OBSERVATIONS on the CONSTRUCTION.

As we differ in some parts of our construction from that given by Mr. Belidor, it will not be improper to acquaint the reader with the reasons that have induced us to do fo. First, We made the length L D, equal to 8 parts instead of 7, to avoid a subdivision of parts; the difference of one part being immaterial. 2. According to our construction, the length G K of the gates comes out to be 7.34 parts nearly; and as Mr. Belidor makes the lines D K one fifth of the width, the length of his gates is 6.46 parts nearly; but as our construction gives the most advantageous position, and that of Mr. Belidor's depends on no fubstantial reasons, we imagine that the disposition here given is preferable to his: It is true, he has endeavoured to prove that his position is that which the gates ought to have, but all his reasoning is grounded upon wrong suppositions; besides, as the length of our gates does not differ above 38 inches in the largest sluice that is made, from the length he gives, we imagine that this difference is more than recompenced by the true position. 3. Mr. Belidor makes the lines MR, QS, 7 parts instead of 4, which difference is very little.

As to the thickness of the side-walls, Mr. Belidor makes it equal to the depth of water in the fluice, in order, as he fays, that they may be fo ftrong as to refift in all accidents that can happen; besides, he adds five counterforts on each fide; their length is equal to the thickness of the wall, and the mean thickness five

eighths of their length.

It is certain, that in constructing such works as these, particular care should be taken to make them strong and durable; yet it ought to be confidered, that by making use of more masonry than is necessary, it encreases the expences considerably, and therefore all exceffes should be avoided.

Now the proper thickness of these walls may be determined in the fame manner as that of those which fupport earth, by comparing the specific gravity of water to that of stone or brick; but it must be observed, that the triangular fection of water has its base at the bottom instead of being above, as in the section of earth: by this method it will be found, that if the thickness of a stone wall be four fifths of the depth of the water, as we have made it, it will be able to support a pressure four times greater than that of the water; which in my opinion is fufficient upon all occasions whatfoever: but when the wall is made of brick, its thickness must be equal to the depth of water, in order to have the fame strength.

Hence it will be found, that the quantity of masonry contained in a fluice, according to our construction, is to the quantity, according to Mr. Belidor's, as 542 to 723, or as 3 to 4 nearly; therefore, if one one fourth of the masonry can be saved, as it appears by what has been faid, without making the walls too weak, the method we propose has greatly the advantage of that

given by Mr. Belider.

It may be observed, that the walls have been supposed to have no slope; but in practice they have, or ought to have one on the outfide, and as there is likewife the pressure of the earth, which helps to support the wall; by these means its resistance is still greater than we have supposed it to be.

It must also be observed, that as the width of the fluice is divided into as many parts as there are inches in a foot; each part will be as many in inches as the width is feet; fo that when the width of a fluice is

given in feet, the value of each part is known; thus if the fluice is to be 42 feet wide, each part will be 42 inches,

or 3 feet 6 inches, and fo in any other cafe.

When a fluice is built in a place where a great quantity of water is to pass, two or more passages are to be made; that is, two or more sluices are built at the side of each other; these passages have sometimes the same width, and at others not, according to the circumstances that render them more useful one way than another.

Whence in a fluice that serves to form an inundation, or to keep up water, these passages are made of an equal width; but in canals and large rivers that serve for navigation, the one is made so wide as that large vessels may go through it, and the other serves for smaller vessels. This has been done in the canal at Mardick, where the largest is 44 feet, and of consequence wide enough for the second rate of men of war to pass through it, and the other is 24 feet, which serves for smaller vessels.

Of the TIMBER-GRATES under the FLOOR and FOUNDATION.

If the foundation be bad, we suppose piles to be driven under the crossings of the sleepers m, and the tie-beams n, in the manner mentioned in the seventh section of the third part; and to prevent the water from getting under the foundation, six rows of dovetail piles are driven, viz. one at each end, one at each of the angles N, P, marked p, and one on each side of the chamber; and it must be observed, that, excepting those at the angles E, P, the rest are all driven between two sleepers, in order to keep them tight and close to gether. The sleepers and tie-beams are partly let into each other, and bolted together; but before this is done, the loose earth is removed from between the sleepers for about two or three feet deep, and filled up with maforry.

fonry before the tie-beams are laid: this masonry is carried on so, as that when a bed of mortar is laid over it, it may be even with the upper surface of the sleepers; then the inside of the sluice is covered with a floor of three inch thick oaken planks, laid long-ways, and nailed to the sleepers; this floor extends a few inches on each side over the foundation of the side-walls, to prevent the water from penetrating through the edges of the floor.

Bricks are used preferably to small stones, to fill up the parts between the grating, as lying much closer. and filling up every part exactly; they are laid in terrass mortar as well as the rest of the foundation. This being done, the frames made to support the gates at the bottom, are laid in their proper places, which are composed of a fell r, two hurters s, two braces v, and a tong t. The fell enters about three feet into the fidewalls, and the fockets to receive the pivots of the gates are placed in it; the tong ought to be fo long as to cross three fleepers, to which it is fastened in a strong man-The fell, tong, and the hurters, ought to have the fame dimensions, and their height must be such as to be a foot above the last floor of the sluice, as well as the floor of the chamber; for which reason, the piles under the chamber are left a foot higher than the rest.

After this another row of sleepers is laid exactly over the first, and a row of tie-beams, so as to answer likewise those underneath; which being let into one another, and bolted together as before, and the vacancies between them being filled up with masonry, and a bed of mortar laid over it, so as to be even with the upper surface of the sleepers; then a second floor is laid, of the same dimensions and extent with the former; and when this is done, the side walls are built in the manner which will be mentioned presently.

Upon the second sloor is laid another of two inch thick planks only, which does not enter the wall, in order that it may be repaired when it is wanted. This last floor may be made of yellow deal, and its seams must be well caulked to prevent the water from pene-

trating through them.

The walls must be made about three seet higher than the greatest depth of water, to prevent the waves from passing over them: the facings are made with the largest stretchers and headers that can be had, laid in terrass mortar, and crampt together; the rest of the work is done with good common mortar.

The foundation must be made larger than the wall, and in proportion to the weight it is to support, and the top must be covered with large flat stones or bricks set long-ways laid in terrass mortar, to prevent the water from penetrating into the masonry, which otherwise

would destroy it in a short time.

When the wall is finished, a bed of clay is rammed against it of two feet thick all round the outside, beginning as low as the foundation, and raised as high as

the wall.

To prevent the water from carrying off the earth by its fall, at the ends of the fluice a false floor of fascines is made of as many fathoms long as the water in the fluice is feet high; this bed or falle floor is funk into the ground as far as is found necessary; but first of all a bed of clay is laid, and well rammed, then beds of fascines are laid long-ways, and fastened with pickets; when the fascines are nearly level with the floor of the fluice, pickets are driven across in rows three feet distant from each other, reaching a little above the fascines, and about each row two branches or poles are twisted of about an inch diameter, so as to cross eac' other between the pickets, which being beat down with a mallet, will keep the fascines very close and tight together; the cavities between these rows of pickets and branches are filled up with a pavement of hard stones a foot long, fet long-ways, well beat down, fo as the curtent may not tear them open. For

For a greater security, a row of dove-tail piles is driven at each end; and it may be observed, that both shoots must have a gradual descent from the chamber of about a 48th part of the length, in order that the water may run off clear, when the sluice is laid dry and

any repairs are wanted to be made.

Aqueducts are sometimes made in the side-walls going round the chamber, and coming out before the gates, in order that the water may pats upon occasion from one side of the sluice to the other, without being obliged to open the gates; they have a shutter near each end, that slides in grooves, which are drawn up, or let down, when there is occasion for it. But as wickets are commonly made in the gates, which may serve for the same purpose, unless on some occasion where the chamber is required to be left dry, and yet it is absolutely necessary that the water should pass from one side to the other; we have therefore not marked them in the plan, but they may easily be made whenever it is thought proper.

The cross-section shews the position of a row of piles, and the fleepers above them into which they are tenoned; the sections of the tie-beams; the floor between them; the fell, and the two floors above it; there is also seen a row of dove-tail piles, broken off in the middle, in order to fee part of the masonry a, a, between the piles and under the fleepers. The outfide of the grates are likewise seen in this section; how the planks are joined to the frame; the shutters x, x, and the irons both of the gate and shutters. In the a construction of gates, particular care should be taken, to join the several pieces together in such a manner, that the whole frame may be as strong as possible, and not to make them heavier than needs must be, to prevent their finking, which is not eafily done in large fluices; nor yet too weak, for fear of their not being able to fustain the great pressure which is against them.

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The principal frame of a grate confifts of two stiles or uprights; that which is next to the wall and to which the pivots are fixed, is called the pivot-post, and the other the chamfered stile, from being edged off on the infide, fo as to make a plain joint with the other gate: these two stiles are joined by two rails which are The other pieces, which are not tenoned into them. feen in this fection, but ferve to strengthen the gate, confifts of feveral rails placed not nearer to each other than 24 inches, nor farther than 30; and of several braces which form the same angle with the pivot-post as the joints of the planks on the outlide, and they are tenoned into the rails; laftly, of two monions or short uprights to form the wickets.

As it is too nice a calculation to find the proper strength of each piece in fuch a manner as may be depended upon in practice, we shall give their dimensions, such as are inserted in Mr. Belidor's works, and which, he fays, have been taken from those most approved of in practice.

The pieces of the principal frame are generally made of the same dimensions, though some will have the chamfered-stile less than the pivot-post, and the rails to diminish gradually; and others say that the gates should be stronger below than above, on account that the preffure of the water is the greatest there; but as the gates are supported below by the hurters, that diminition ought rather to begin at about one third of the height distant from the bottom. However, we shall suppose the pieces of the principal frame to be of the same dimenfions, which are as follows. In all fluices from 8 to 12 feet wide, the pieces of the principal frames are to be 8 inches thick, and 10 broad; the intermediate rails 6 by 8; the braces and monions 4 by 6; and the whole covered with two-inch thick planks as well as a l the gates of fluices under 37 feet wide.

In fluices which are from 13 to 18 feet wide, the pieces of the pricipal frame are to be 10-by 12 inches; the intermediate rails 8 by 10; the braces and monions

4 by 6. In fluices from 19 to 24 feet wide, the pieces of the principal frame are to be 12 by 14 inches; the intermediate rails 10 by 12; the braces and monions 5 by 7. In fluices from 25 to 30 feet wide; the pieces of the principal frame are to be 14 by 16; the intermediate rails 12 by 13; the braces and monions 6 by 8. In fluices from 31 to 36 feet wide; the pieces of the principal frame are to be 15 by 17 inches; the intermediate rails 13 by 14; the braces and monions 7 by 9. It must be observed, that when the gates are very high, the middle rail is made of the same dimensions as those in the principal frame.

In all fluices from 37 to 42 feet wide, the pieces of the pricipal frame are to be 16 by 18 inches; the intermediate rails 14 by 16; the braces and monions 7 by 9; and covered by planks of two inches and a half thick; or rather with two rows of planks of that thickness, in order that the seams of the under row may be covered by the upper one. Lastly, in all sluices which are from 42 to 48 feet wide, the pieces of the principal frame are to be 18 by 20 inches; the intermediate rails 15 by 18; the braces and monions 8 by 10; covered by planks of two inches and a half thick as before.

It may be observed, that these dimensions depend on the width of the sluice only; the depth of the water has not been considered, though it should have been done; since the greater that depth is, the pressure is likewise the greater, when the rest is the same; consequently the dimensions here given must be increased in great

depths, and diminished in small ones.

As to the number and strength of the irons in the gates of a sluice, they ought to be in proportion to the largeness and weight of the frame; the principal ones in small sluices are reduced to two straps, which serve to bind the under and upper rails to the pivot-post, which they embrace on both sides; they are let into the wood, so as to be even with the surface of the gate, and fastened with 5 or 6 iron bolts riveted with burrs, or with

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rings and keys; the length of these straps ought to be about one third of the width of the gate. Sometimes the chamfered-stile is bound to the rails above and below, with strait straps like the former, but oftener with bent ones, such as are represented in the section, one on each fide, bolted together in the same manner as the former.

When the gates belong to a large fluice which contains a great depth of water, the middle rail is likewise bound to the pivot-post, and the chamfered-stile by two straps in the form of a T, both within and without, bolted together as before; and when the gates are very large, two straps are used to fasten the upper rail to the pivot-post, because the greatest stress lies in that part; and to secure it still more, another strap is bolted upon the edge of the upper rail, and bent against the pivotpost; this last strap is of grater use to keep the gate from finking than any other, for which reason, it is seldom

omitted, whether the gates be small or large.

The various contrivances that are made to open and thut the gates, require some notice to be taken of them; but as in so small a work as this, it is not possible to give a compleat description of every particular part; they therefore must be left to the sagacity and prudence of the builder. It must be observed that as the wickets are made to let the water into the chamber before the gates are opened, in order to ease them from the great pressure of the water on the outside; there feems to be no reason for placing them so low, nor so far from the pivot post as is commonly done; for provided they are low enough to let in fo much water as will rife to the fame level within as it is without, it will be fufficient; consequently the lower part of the wickets should never be below the middle height of the water without, whereby the weight of the irons will be diminished. And the nearer the wickets are to the pivotposts, the less the pressure would be upon the gates, when the wickers are to be opened; besides, all possible means should be used, to lighten the farther end of the gates, to prevent their sinking, which they will do nevertheless, especially when they are large: this however may be remedied, by placing brass-casters under them, at above two thirds of their width from the pivotpost; but then a piece of timber must be placed upon the floor, of a circular form, for the roller or caster to

move upon.

Sometimes the gates of large fluices are made in the form of a part of a cylindric furface, whose base is a twelfth part of a circle; this is done in view to strengthen the gates against the pressure of the water; in such a case the curve of the rails must be natural, and according to the grain of the wood, otherwise the gates will become weaker instead of being stronger; since a scantling cutacross the grain of the wood will always be weaker than any other of the same dimensions, and the same kind of timber.

Various methods are used to shut sluices under twenty four feet wide: in sluices from ten to sisteen feet wide, a single gate is made, which is sometimes opened by means of a capstane; at others the upper rail of the gate is made so as to go beyond the pivot-post, and from thence made much thicker and heavier, to be a kind of a counter-balance to the gate; the end of which being pressed downwards by several people, and then turned

round, opens the gate eafily.

Sometimes single gates are used of a much larger size than the former; these gates have their pivot-post nearly in the middle; so that the largest part of it turns towards the stream when the gate is to be opened, and the least the contrary way. The pivot-post must be placed in such a manner, that the pressure of the water against the largest part may keep the gate shut close, and at the same time that there may not be too great difficulty to open it. It has been found by experience that when the pressure against the largest part exceeds that against the lesser by one sixth part, it is sufficient; whence

whence it is eafily proved from the known principles of hydrostatics, that if the width of the smallest part is to the width of the largest, in the proportion of 12 to 13, it will answer the said proportion of the pressure.

These gates are certainly the most convenient that can be; but as there must be laid a strong timber across the fluice to support the upper pivot, no vessels that have masts can pass through them; for which reason, they cannot be used but in sluices that serve to keep up the water for raising an inundation, or in those that are built at the entrance of a canal, which runs into a harbour, for the fake of clearing and carrying away the fand and shingle that have been driven in by the tides.

Wickets have been made in this manner, and found very convenient; because the great pressure of the water against the common fort, makes their opening very troublesome; whereas this fort are opened and shut

with great ease, and very little labour.

Sometimes fluices are made in fortresses at the side of stone-bridges; this is done by making the piers to project beyond the bridge, and in the projected part cullifes are contrived fo as to let down fquare timbers, which being kept close and tight, the water may be raised to any height: in short, many other forts of sluices are made upon various occasions, which it would be inconvenient to mention in this work.

Of AQUEDUCTS.

The intent of aqueducts is generally to bring water from a fpring or river to a town, but they are likewise used to carry canals over low ground, and over brooks or small rivers: they are built with arches like a bridge, only not so wide, and are covered above by an arch to prevent dust or dirt from being thrown into the water. The ancient Romans were remarkably curious in these forts of works, for they not only supplied all the parts of Rome with water for common uses, but likewise for a great number of public baths; and that nothing might be

be wanting, created a public magistrate, whose only business was to take care of them, either to repair those already made, or to construct new ones where they were wanted; sometimes the same work served for both a bridge and aqueduct; then the water was led through two covered canals, one on each side of the road, for

carriages.

As these kinds of aqueducts differ very little in their construction from common bridges, of which we have treated before, we shall not enter into any paticulars here concerning them; but when a canal is to pass through a country crossed by rivers, it must be observed how high, in respect to the bottom of the canal, the water rises at the time of its greatest flood, in order to know whether these waters can be carried under the bottom of the canal by means of aqueducts, and have yet a sufficient declivity to run off.

The fame thing is to be observed in regard to those arising from the rains and the melting of the snows, which when led into a ditch made along the highest side of the canal, may from thence be carried off to the other side underneath the canal: These waters should never be carried into the canal, unless it be impracticable to do

otherwise.

It requires great precaution, as well as circumspection, in determining the place of aqueducts, so as to give them sufficient roomwhen they have but one passage, which is to be widened at the entrance, and at the outlet in a proper manner: if there is not a sufficient depth to construct one of such a bigness, as the quantity of water that is to pass requires, two or more passages must be made at the side of each other, to prevent an inundation, that otherwise might ensue; but it must be observed, to make them in such a manner as to be easily cleared from the sand and mud deposited there by the water, for want of its having a sufficient velocity.

Therefore,

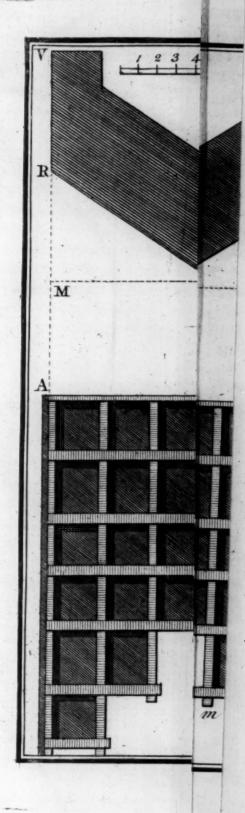
Therefore, when the water on both sides is nearly level with that in the canal, it must be avoided as much as possible, to make the aqueduct in the form of a syphon, in order to carry the waters under the bottom of the canal; but rather to let the water into the canal on the highest side, and out on the other, by means of small sluices with shutters.

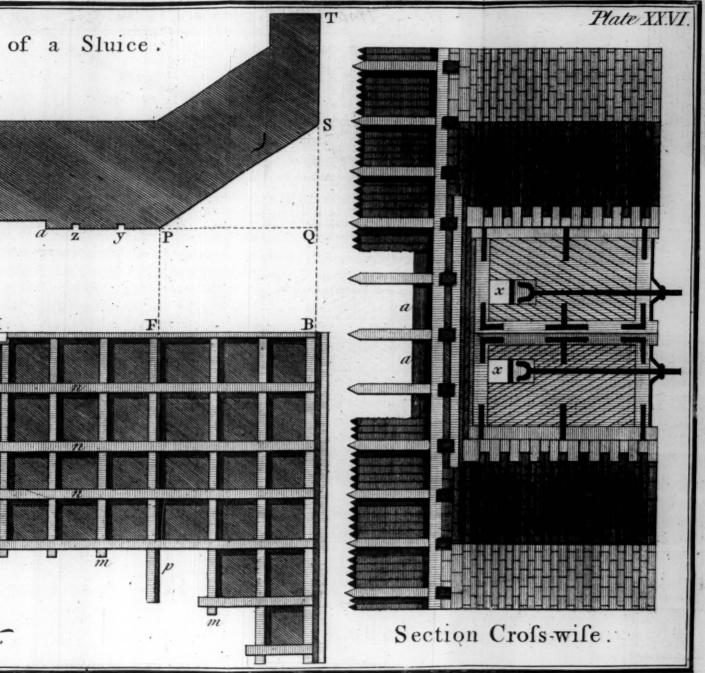
When the waters are below the bed of the canal, it is carried over them by means of an aqueduct, in the form of a bridge with several arches, through which the water passes; there are many of this kind in the famous canal of Languedoc. In this case, after having determined the interval between the two abutments, according to the quantity of water that is to pass through the arches in the time of the greatest flood, and agreed on the number of arches, in respect to the width it is convenient they should-have, so as not to multiply the number of piers without necessity, for fear of diminishing the passage of the water; in short, after having taken all the necessary precautions, in consequence of the level of the canal, to determine the height of the arches, and their thickness at the keystone; then the parts between the arches are filled with good masonry to make the upper part level, and a bed of cement is laid all over, with the same care and manner as has been explained in the fection where we have treated of under-ground arches, to prevent the water of the canal from penetrating through any part of the arches, which otherwise would destroy them in a short time, were this precaution not used.

The width of the aqueduct must be such, that the largest vessel used may pass conveniently; or if the canal is much frequented, it ought to be such, that two or more vessels may pass a-breast; and at the sides passages are also made for the horses which draw the

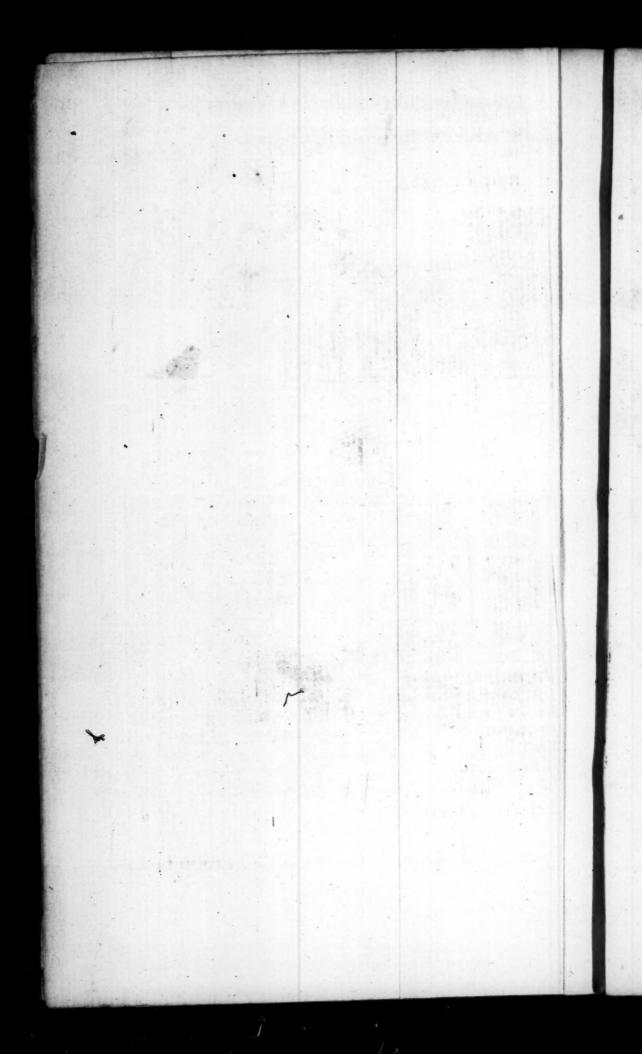
yessels.

When the furface of the waters is nearly level with the bottom of the canal, the aqueduct must be lower in the





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the middle than at the ends; in fuch a case, cess pools must be made on each side, of sufficient depth and breadth, so that the water may run in first there, to settle and deposite its mud, before it passes through the aqueduct; but this should never be done when it is possible to do otherwise, by placing the aqueduct either something higher up the canal, or lower down.

Besides those kinds of aqueducts we have mentioned already, there are others placed on the tops of hills, which serve as a reservoir for water to be from thence earried through pipes into gardens to make water-works for pleasure: and the water is brought into them, by means of pumps and other engines; the most famous one of this fort, in Europe, is that at Marky; and as it is admired by all travellers that have seen it, the reader will perhaps be pleased with a description of it, which we have made upon the spot, in company with some other gentlemen.

The length of this famous aqueduct is 400 yards, and supported by 36 arches; its greatest height is 82 feet, and lowest 75 feet, so that the slope of the canal is about 7 feet from the highest part to the lowest; the width of the arches is 8 yards, and the height of the highest 52 feet, the breadth of the piers is equal to the width of the arches, that is yards, and their thickness 5 yards below reduced to 7 feet above, because the building has a slope on each side; the walls which inclose the canal of the water are each a foot and a half thick, and an arch goes over it; so the canal is about 4 feet wide, and about the same height in the middle.

This aqueduct is 500 French feet above the furface of the river Seine, and at 1220 yards distance from it as this height is too great for a single fet of pumps to force the water up at once, let them be ever so strong; it has therefore been divided nearly into three equal parts: the first set of pumps raises the water to a height of 150 feet, the next set, which is 300 yards distant from the river, raises it 175 feet, the third set, which

is 648 yards from the river, raises the water up to the

aqueduct, that is 175 feet more.

From this aqueduct, two pipes of 18 inches diameter lead the water into a bason at Marly, and from thence it goes to the fever fountains in the garden; there is likewife another pipe of 8 inches diameter that leads the water from the aqueduct to Versailles.

There are 253 pumps employed to force the water up to the aqueduct, and from the last set it is carried up by 6 pipes, each being 8 inches in diameter the quantity of water raised formerly in a day was 779 cubic fathoms, but at present, it raises scarcely above half that quantity; which may be owing to some decay in the

machine, or neglect in its repair.

Notwithstanding the wounderful contrivances of the author (one Ranequin of the country near Liege) in the disposition of the several parts of this machine, yet many pretended judges find fault with it; though none of them are capable to invent a new one that can be compared to this; but it is customary amongst the present virtuosi, to find fault with the performances of their mafters, and think themselves better skilled than those they can barely imitate.

But amongst the critics of this wounderful machine, I except Mr. Belidor, who has really shewn some defects in the bodies of the pumps, and at the same time, how they might be amended: and as he has given a full defcription of it, together with proper plans and fections, we refer the reader to his works for a full account of this machine, which we have only mentioned, as being partly connected with the aqueduct, the description of which

alone we proposed to give here.

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